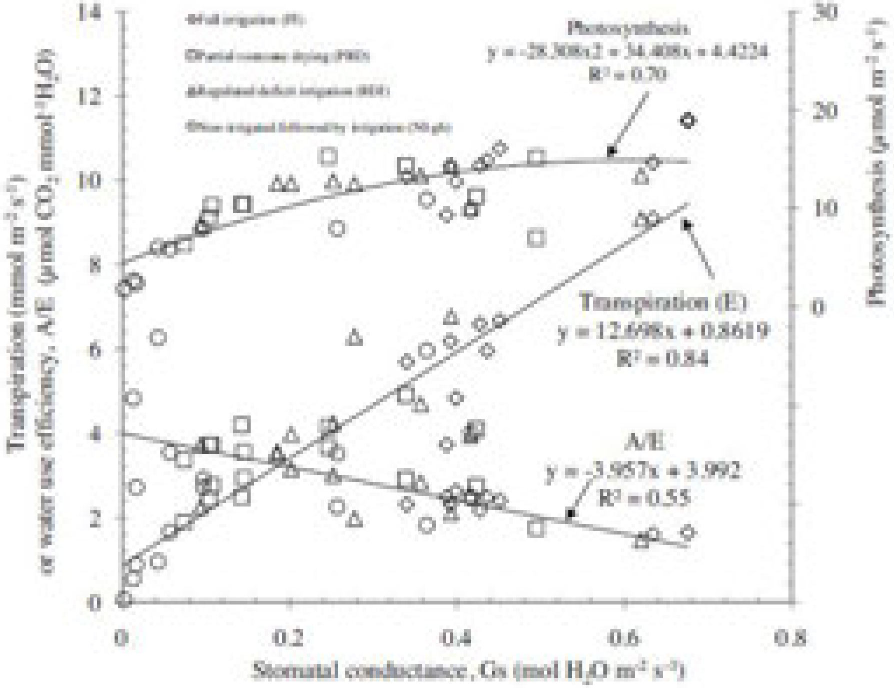


Fig. 3. Relationship of stomatal conductance (G_s) to transpiration (E), photosynthesis (A) and water use efficiency (A/E) for papaya treated with four irrigation regimes.

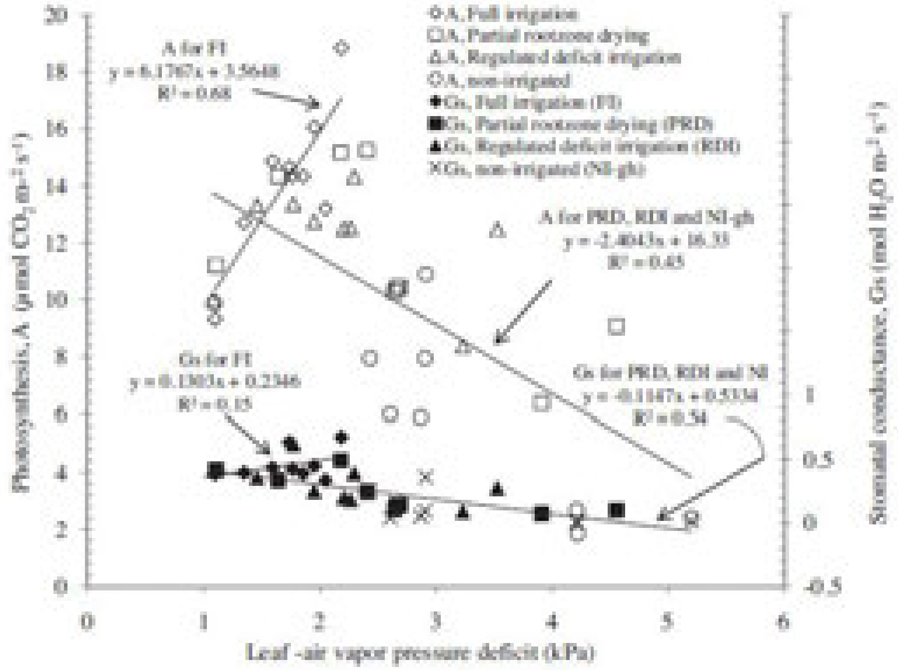


Fig. 5. Relationship of photosynthesis to stomatal conductance with the leaf-air vapor pressure deficit in papaya treated with four irrigation treatments in the greenhouse.

Photochemical efficiency of PSII

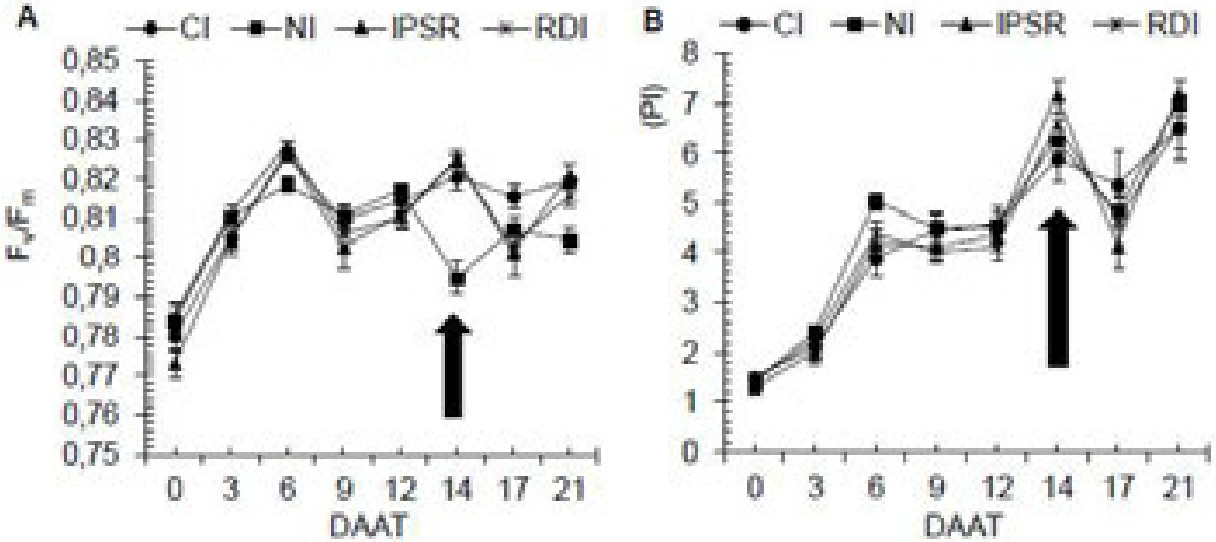
PI=(RC/ABS) x (TR/DI) x (ET/(TR-ET))

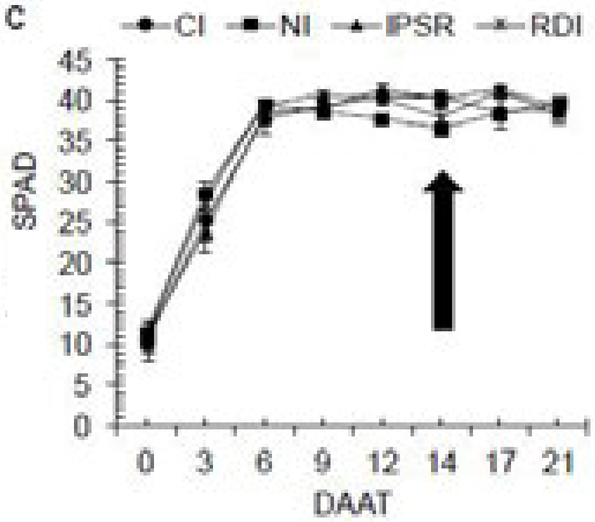
(RC/ABS): Active RC density on a Chl basis

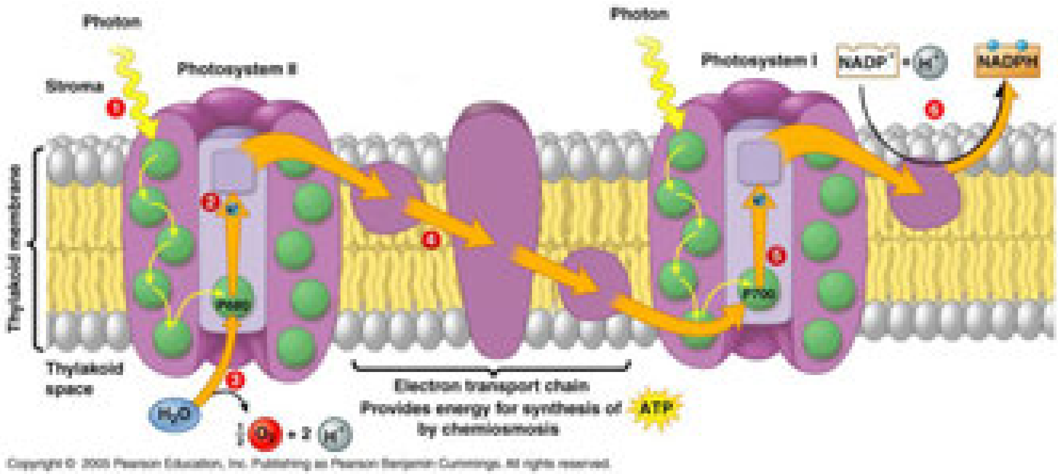
(F_V/F_0): Performance due to trapping probability $F_v/F_0=TR/DI$

(ET/(TR-ET): Performance due to electron-transport probability

$F_v/F_m= TR/ABS$







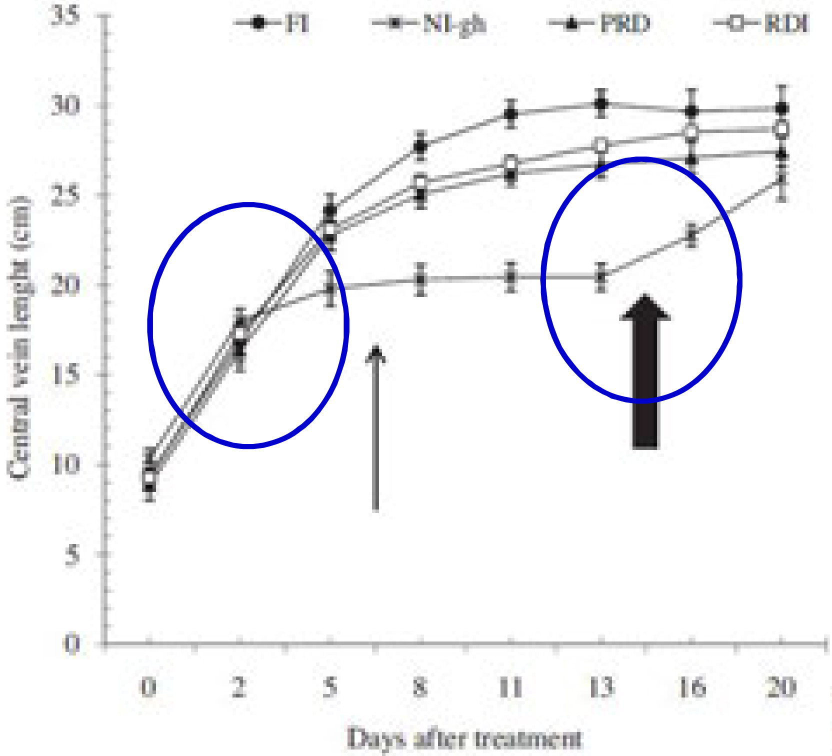


Fig. 7. Central vein length during the ontogeny of the youngest leaf of each plant ('Grand Golden' papaya) in splitroot pots under four different irrigation regimes: FI, NI-gh, PRD, RDI. The narrow and broad arrows indicate the first alternating between the two root sides of the PRD pots and rehydration of NI treatment, respectively ($n = 10$).

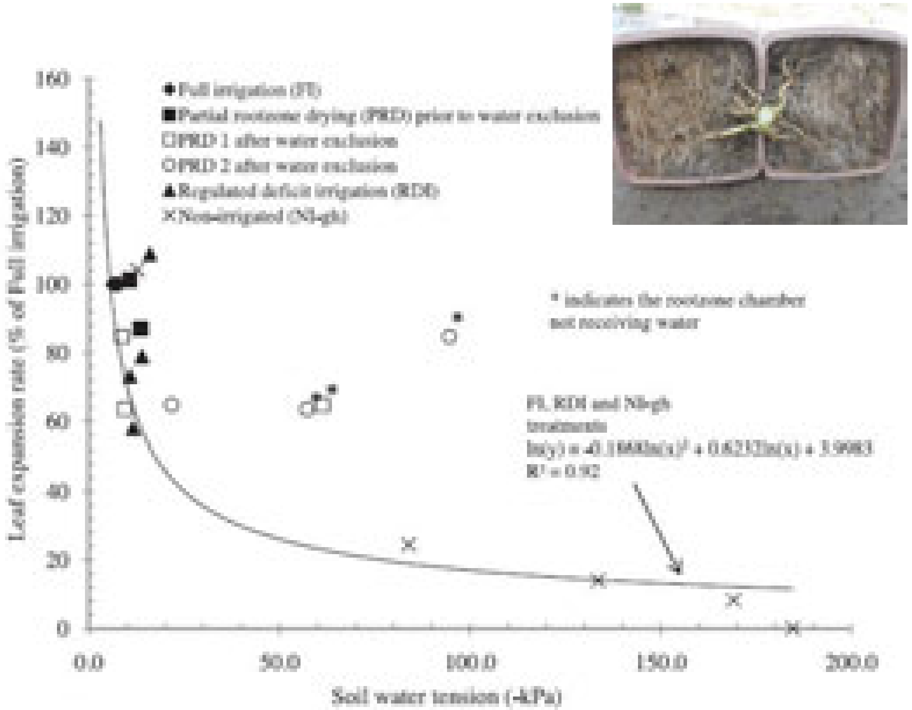
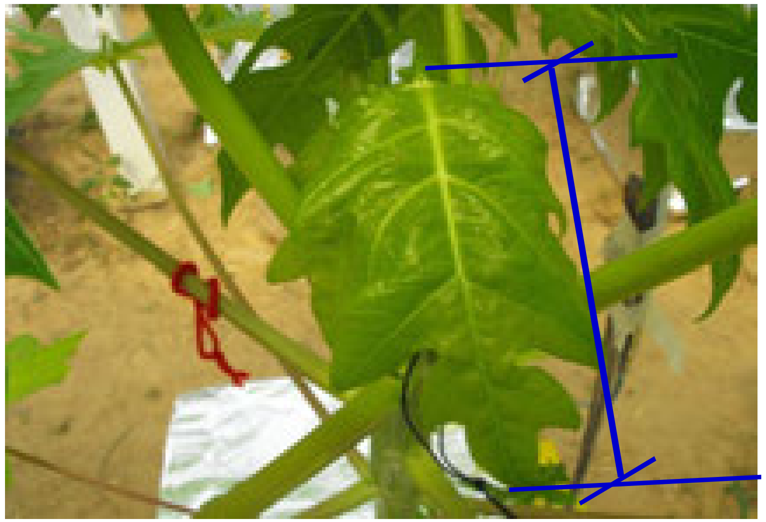
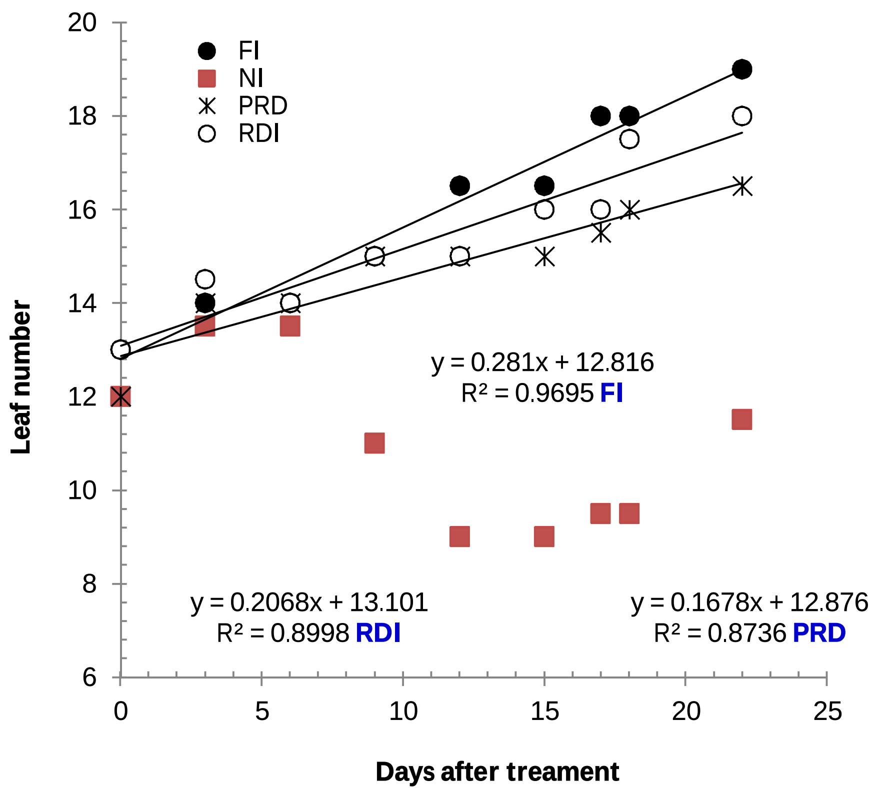
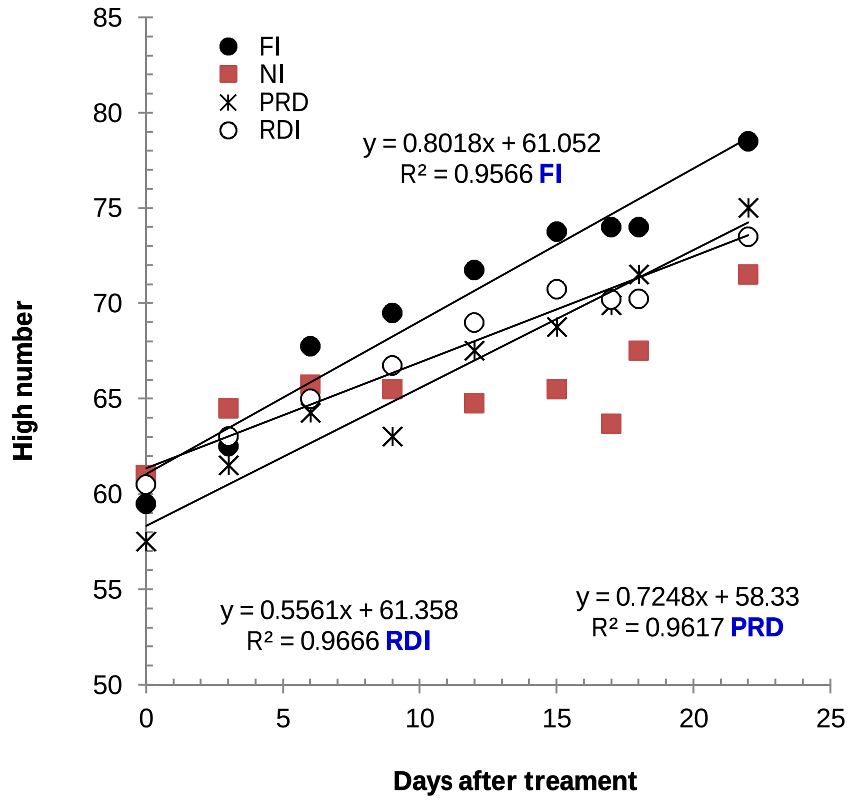


Fig. 11. Relationship between incremental leaf growth (% of full irrigation) and soil water potential in papaya in four irrigation treatments in the greenhouse.





20
18
16
14
12
10
8
6
FI
NI
PRD
RDI
y = 0.281x + 12.816
R² = 0.9695 FI
y = 0.2068x + 13.101
R² = 0.8998 RDI
y = 0.1678x + 12.876
R² = 0.8736 PRD
Leaf number
0
5
10
15
20
25
Days after treament



85
80
75
70
65
60
55
50
FI
NI
PRD
RDI
y = 0.8018x + 61.052
R² = 0.9566 FI
y = 0.5561x + 61.358
R² = 0.9666 RDI
y = 0.7248x + 58.33
R² = 0.9617 PRD
High number
0
5
10
15
20
25
Days after treament

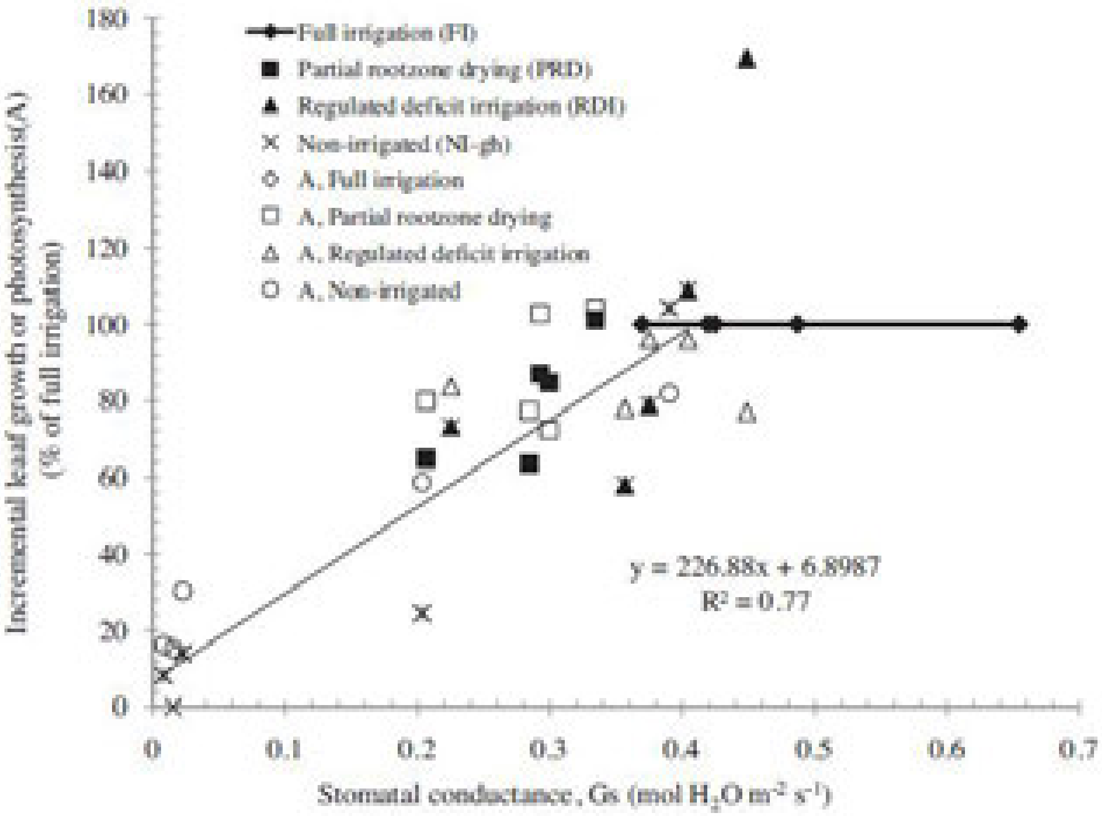


Fig. 12. Relationship of stomatal conductance (G_s) to incremental leaf growth and photosynthesis (A) in papaya in four irrigation treatments in a greenhouse.

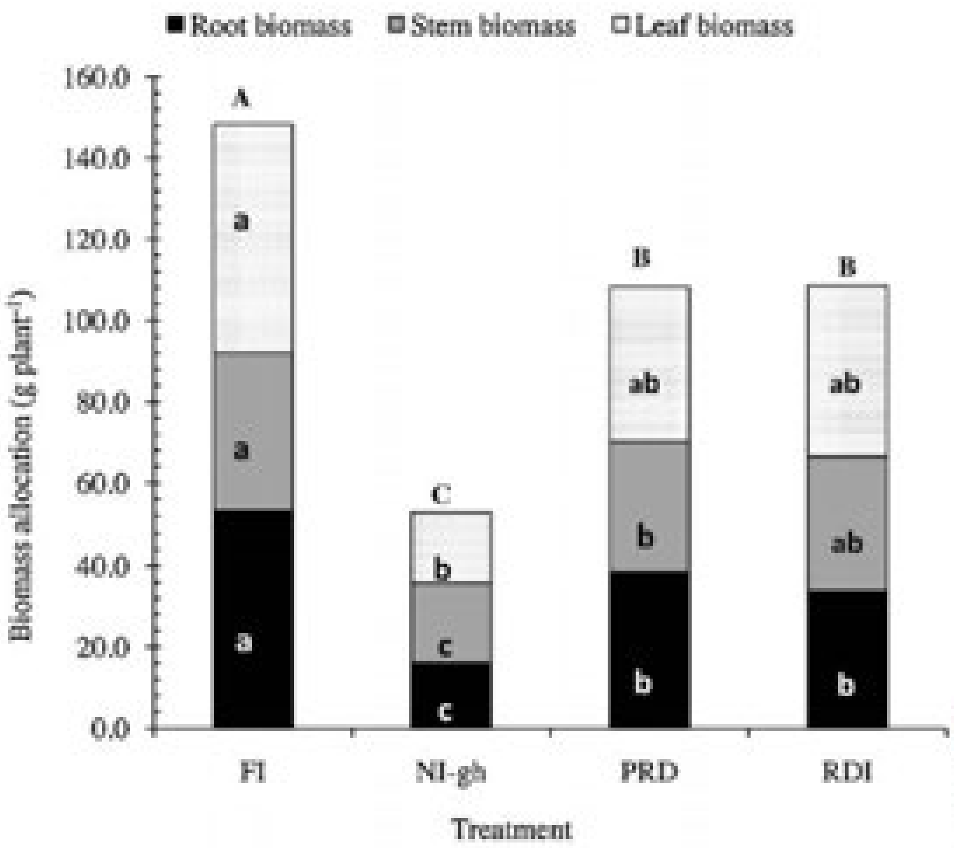


Fig. 8. Biomass allocation of leaf, trunk and root (g dry weight plant^{-1}) tissues in papaya treated with four irrigation regimes in the greenhouse. FI, NI-gh, PRD, RDI. Capital letters refer to mean separation between treatments. Lower case letters refer to mean separation within the three tissue components (*P* = *0.05*).

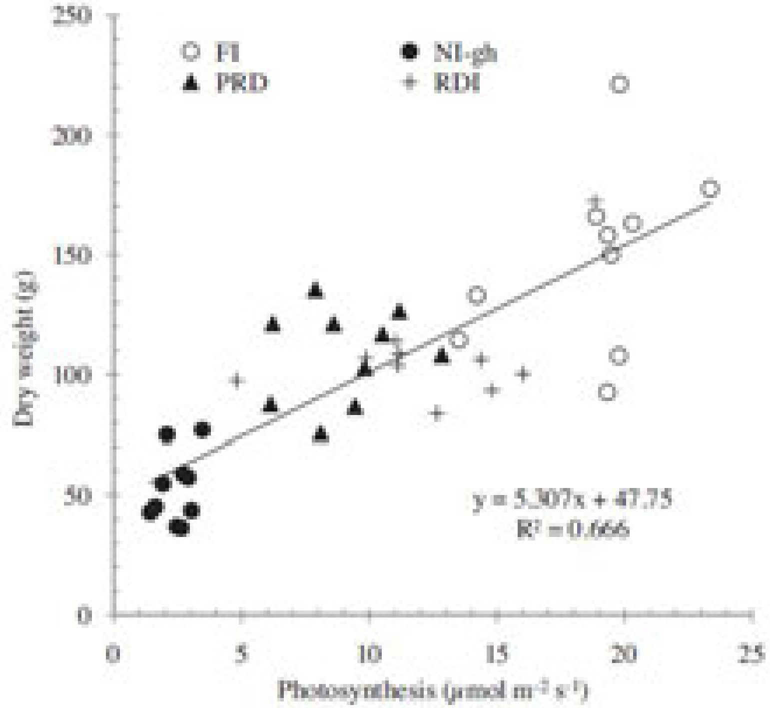
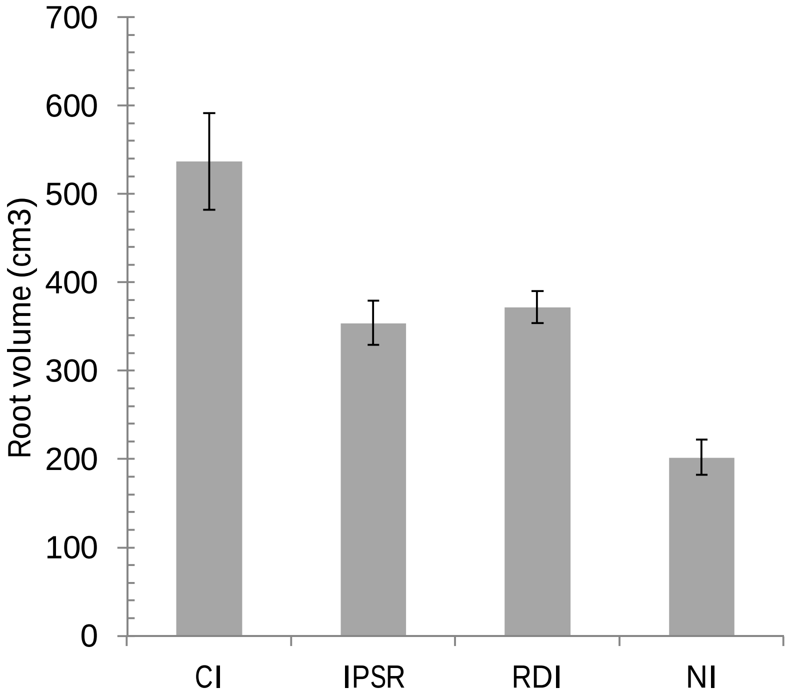
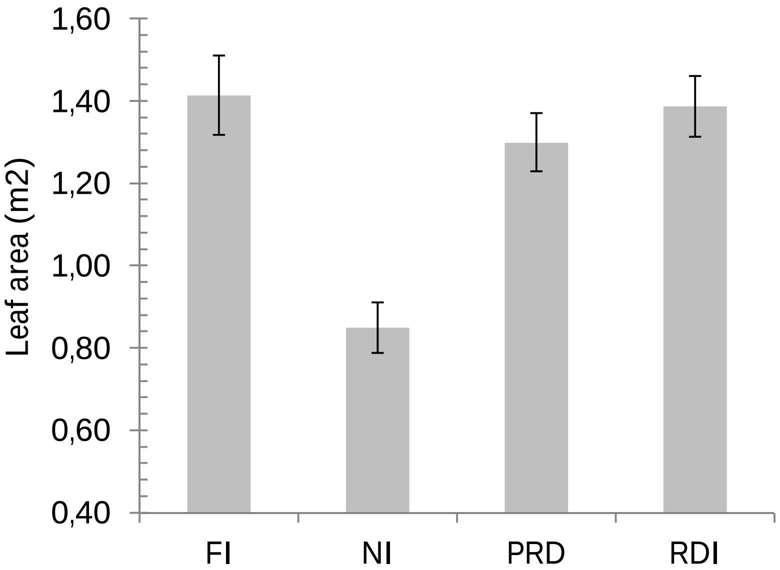


Fig. 9. Relationship of photosynthesis to dry weight 14 days after initiating treatments (the day of most intense water stress for the plants in NI-gh) in 110-days-old 'Grand Golden' papaya plants grown in splitroot pots under four different irrigation regimes (FI, NI-gh, PRD, RDI) in a greenhouse. Values represent means of 10 replicates.


Root volume (cm3)
700
600
500
400
300
200
100
0
CI
IPSR
RDI
NI


Leaf area (m2)
1,60
1,40
1,20
1,00
0,80
0,60
0,40
FI
NI
PRD
RDI

FI

NI

RDI

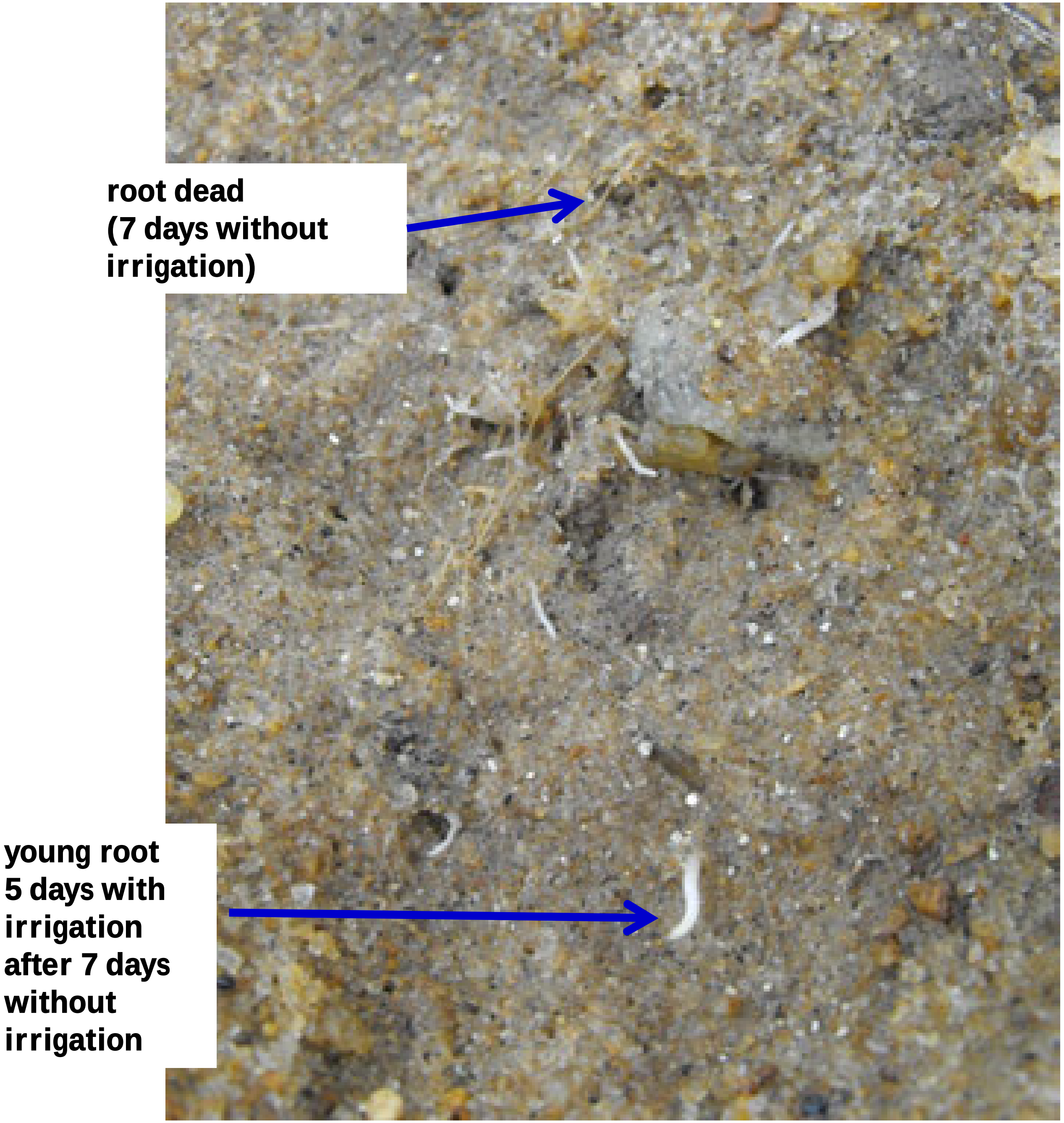
PRD

FI

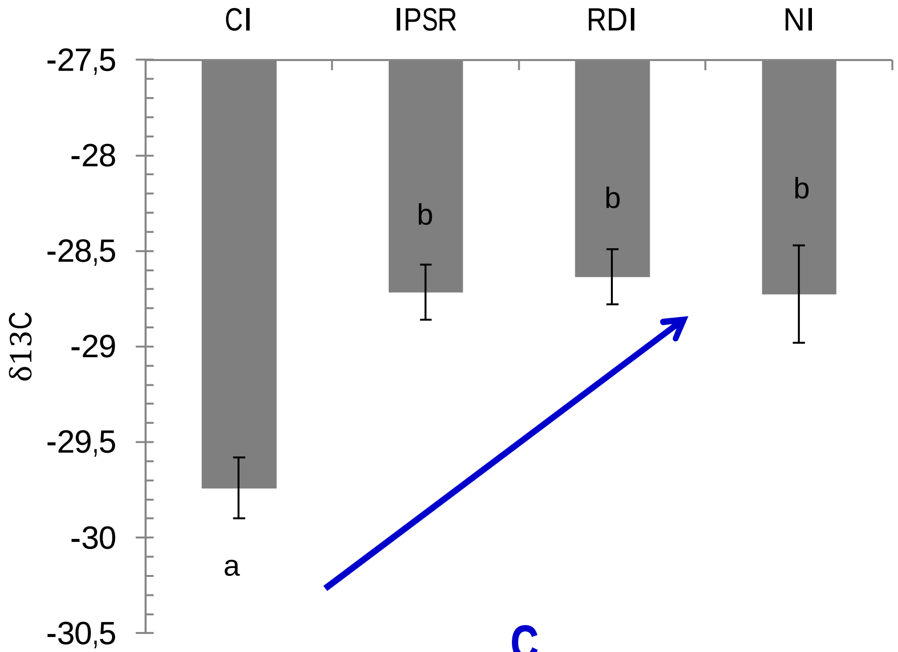
FI

NI

Dry side of PRD

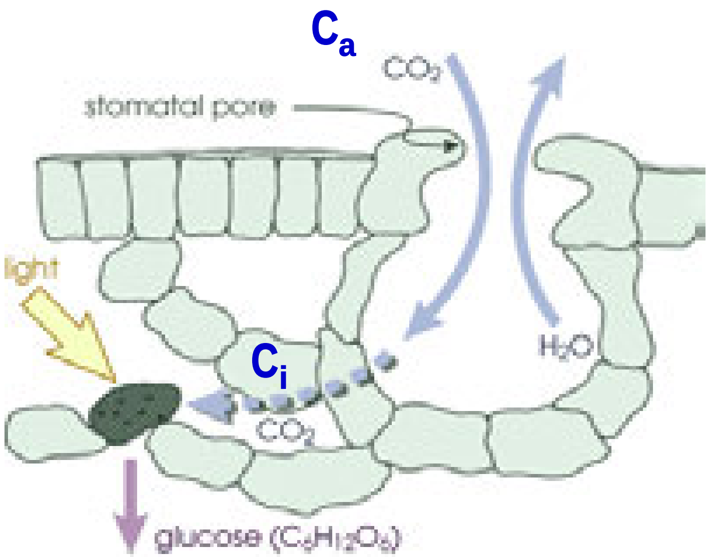

root dead
(7 days without
irrigation)
young root
5 days with
irrigation
after 7 days
without
irrigation

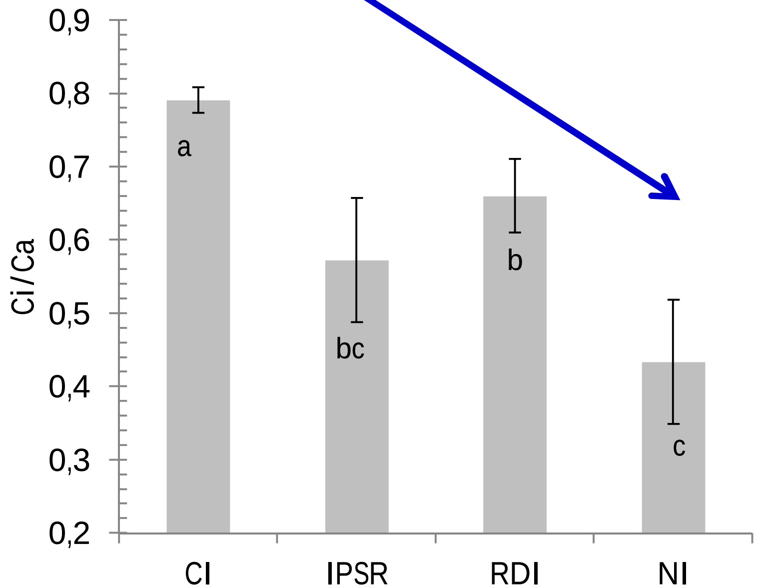
Carbon isotope discrimination



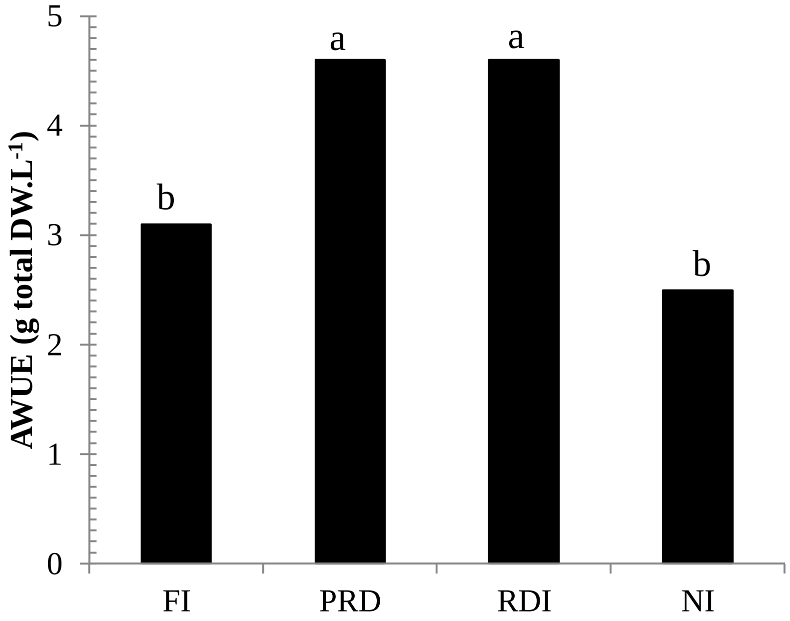
$>C_i/C_a$ (≈0,7) = **< δ ‰**

$<C_i/C_a$ (≈0,3) = **> δ ‰**





Agronomic water use efficiency



Treatment	Water economy in relation FI (%)	AWUE (g DM L^{-1})	Transpiration rate (L H_2O g DM^{-1})
FI	-	3.12	0.322
PRD	**50%**	4.55	0.217
RDI	**50%**	4.57	0.217
NI	55.14%	2.46	0.400

C3 crops
1 to 6 g DM L^{-1} H_2O

C4 grasses
10 to 30 g DM L^{-1} H_2O

Arkley (1982)

Table 1
Total volume of water applied, and volume applied per day of greenhouse-grown papaya (*Carica papaya* L.) in splitroot pots with four different irrigation treatments: full irrigated (FI), Partial Rootzone Drying (PRD), Regulated Deficit Irrigation (RDI), and non-irrigated followed by 6 days of FI (NI-gh).

Treatment	Total volume of water applied (L)	Volume of water applied per day (L)
FI	47.50	2.3
PRD	23.8	1.1
RDI	23.8	1.1
NI-gh	21.3	1.0

Treatment	L H_2O m^{-2} day^{-1}
FI	1.63
PRD	0.84
RDI	0.78
NI	1.17

Treatment	Volume water applied per plant per day	Transpiration L H2O per m² leaf per day per plant	Transpiration L H20 per plant per day	Leaf area m2	age
Whole canopy summer	16.0	2.5	10	4.0	5 months
Whole canopy winter	10.0	4.2	15	3.5	5 months
FI	2.3	1.63	2.3	1.41	3 months
PRD	1.1	0.84	1.1	1.30	3 months
RDI	1.1	0.78	1.1	1.40	3 months
NI	1.0	1.17	1.0	0.85	3 months

Thermal imaging

G Model
AGWAT-4235; No. of Pages 10

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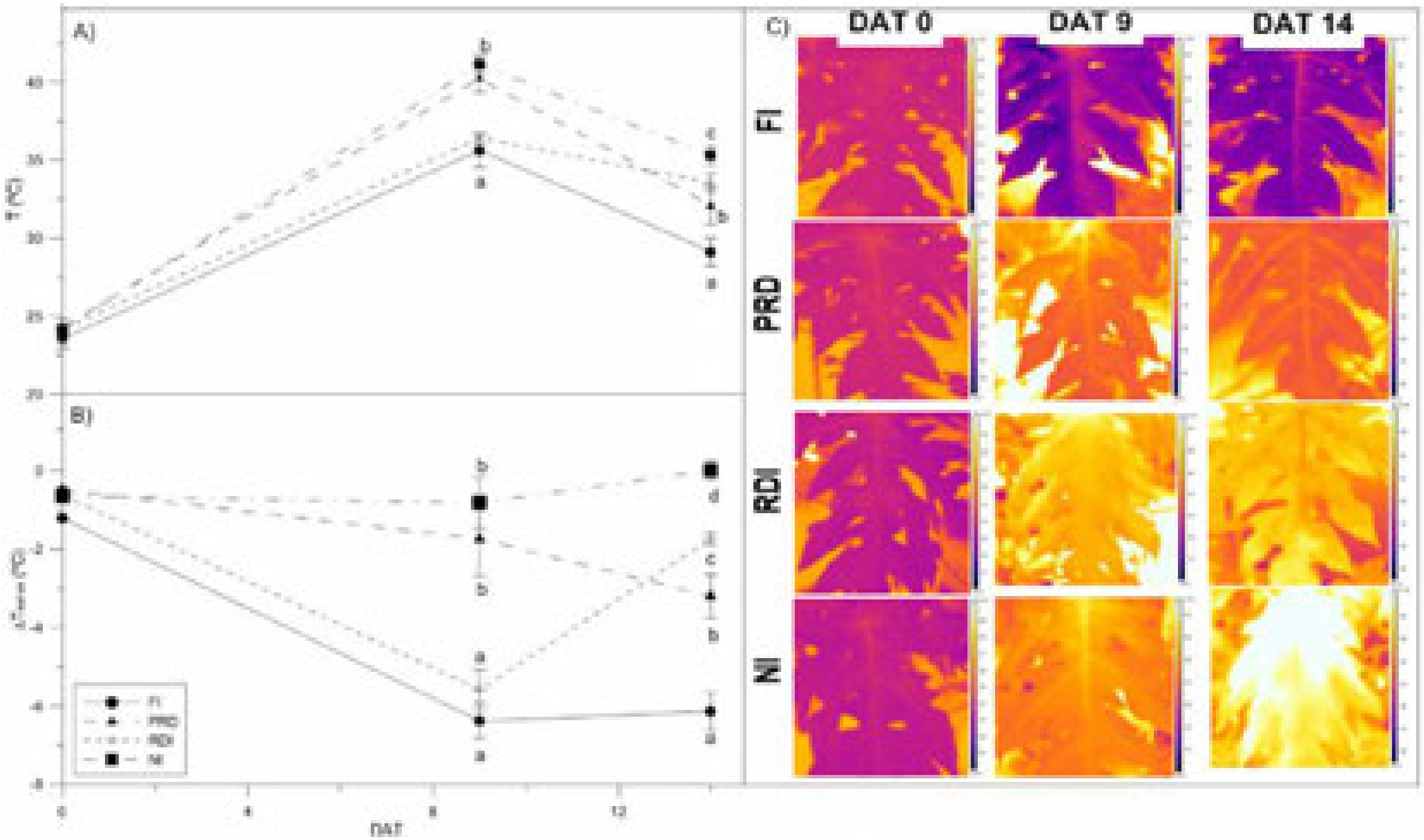

Fig. 3. (A) Leaf temperature (T_{leaf}) derived from IR measurements during the study (DAT); (B) difference of leaf to air temperature ($\Delta T_{leaf-air}$), and (C) false-colored IR thermal images showing a selected fully expanded leaf, along the experiment for the different treatments: fully irrigated (FI); partial root drying (PRD); regulated-deficit irrigation (RDI); non-irrigated (NI). Climate conditions at 0 DAT (T_{air} max: 25 °C, RH_{min}: 80%, ϕ_{soil} = −10 kPa, PAR_{max} = 257 μmol m^{-2} s^{-1}); 9 DAT (T_{air} max: 44 °C, RH_{min}: 26%, PAR_{max} = 900 μmol m^{-2} s^{-1}) and 14 DAT (T_{air} max: 36 °C, RH_{min}: 39%, PAR_{max} = 830 μmol m^{-2} s^{-1}). Leaf temperature scale is identical for four treatments in the same day of observation. Different letters indicate significant differences at $P < 0.05$ by the Tukey's test ($n = 10$).

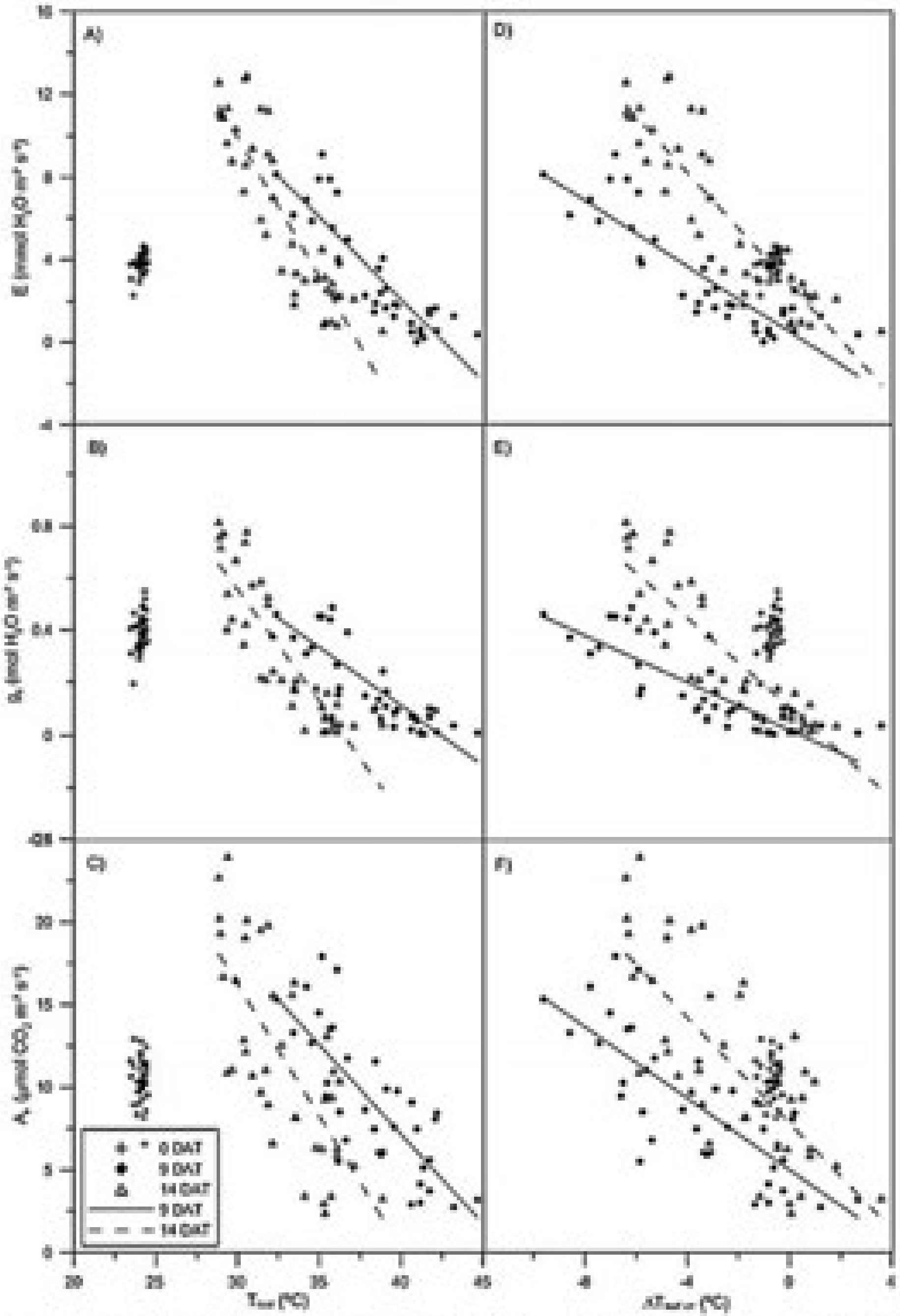

Fig. 4. Relationship between transpiration (E), stomatal conductance to water vapor (g_s) and net assimilation (A_N) vs. the leaf temperature (T_{leaf}) and the difference between T_{leaf} and air temperature ($\Delta T_{leaf-air}$). Each linear function was determined with 80 pair of data (n = 80).

Agricultural Water Management

Linking thermal imaging to physiological indicators in *Carica papaya* L. under different watering regimes

R.S.N Lima, I. García-Tejero, T.S. Lopes, J.M. Costa, M. Vaz, V.H. Durán-Zuazo, M. Chaves, D.M. Glenn, E. Campostrini

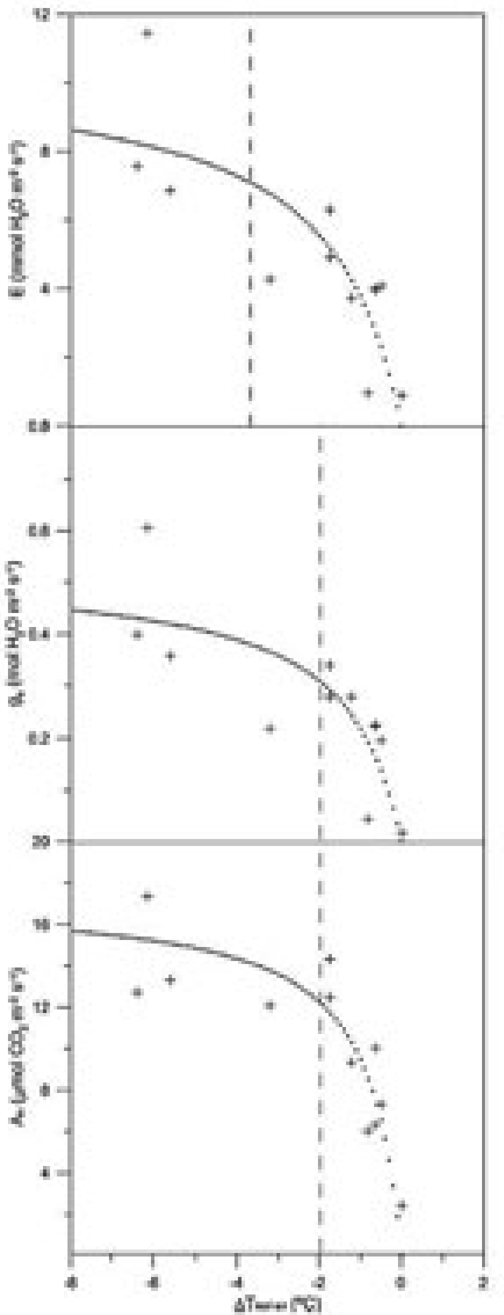

Fig 5. Relationship between air temperature ($\Delta T_{leaf-air}$), stomatal conductance (g_s) and net photosynthesis (A).

Scientia Horticulturae 183 (2015) 13–22

Contents lists available at ScienceDirect

Scientia Horticulturae

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Partial rootzone drying (PRD) and regulated deficit irrigation (RDI) effects on stomatal conductance, growth, photosynthetic capacity, and water-use efficiency of papaya☆

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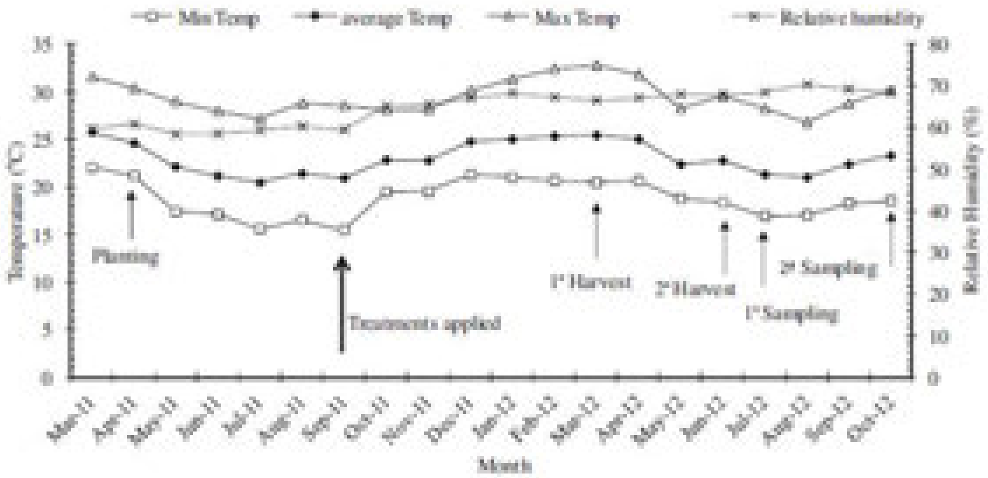
[c] USDA-ARS, Appalachian Fruit Research Station, 2217 Wiltshire Road, Kearneysville, WV 25430, USA

20 months
Caliman company
Brazil
http://www.caliman.com.br/pt/

Field condition

Field condition



Treatment[a]	Irrigation + precipitation (L)
FI	2698
NI-field	1025
PRD100	2698
PRD70	2189
RDI	2189
FI	3755
NI-field	1107
PRD100	3755
PRD70	2949
RDI	2949

ET_0

measurement period (Jones, 1992). The meteorological station was installed 100 m the experiment, and the data were used to calculate the reference evapotranspiration (ET_0) using the Penman equation parameterized by the United Nations Food and Agriculture Organization (FAO) (Pereira et al., 1997) (Eq. (1)). We considered that the daily balance heat flow in soil was zero ($G = 0$).

$$ET_0 = \frac{s}{(s+\gamma^*)}(Rn - G)\frac{1}{\lambda} + \frac{\gamma}{(s+\gamma^*)(T+275°)}U_2(e_s - e_a) \quad (1)$$

where: s is the slope of the vapor pressure curve (kPa °C^{-1}); γ^* is the modified psychrometric constant (kPa °C^{-1}); Rn is the net radiation (MJ m^{-2} d^{-1}); G is the heat flow in soil (MJ m^{-2} d^{-1}); λ is the latent heat of evaporation (MJ kg^{-1}); γ = psychrometric coefficient (kPa °C^{-1}); T is the average temperature (°C); $U2$ is the wind speed at 2 m (m s^{-1}); e_s is the saturation vapor pressure (kPa); e_a is the partial pressure of vapor (kPa).

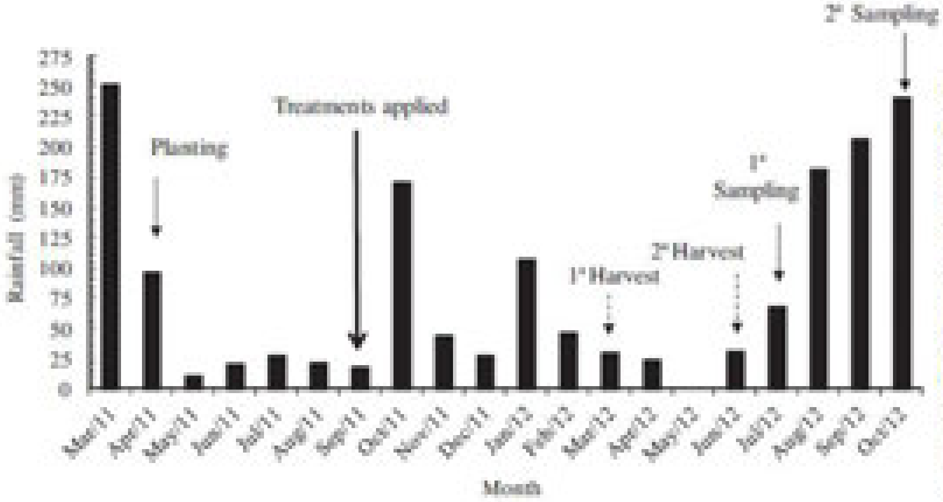


Fig. 2. Meteorological variables in a field study.

to 5-month-old plants: [illegible] was applied on both sides of the root with 1 drip line and 2 emitters per plant (0.75 m emit- [illegible] ow was 2.3 L h^{-1} (total flow: 4.6 L plant^{-1}); [illegible] applied to one side only of the root, and [illegible] as applied to the alternate side of the root system. Water was applied with 2 drip lines and 2 emitters per plant (0.75 m emitter [illegible] tter flow was 2.3 L h^{-1} (total flow: 4.6 L plant^{-1}); [illegible] was applied to one side only of the root, and eve [illegible] was applied to the alternate side of the root system to allow always a part of the root system experience a mild water stress. Water was applied with 2 drip lines and 2 emitters per plant (0.50 m emitter spacing). Emitter flow was 1.6 L h^{-1} (total flow: 3.2 L plant^{-1}); [illegible] was applied to both sides of the root system. Water was applied with 1 drip line and 2 emitters per plant (0.50 m e [illegible] Emitter flow was 1.6 L h^{-1} (total flow: 3.2 L plant^{-1} [illegible] non irrigated received only natural rainfall. There was only one soil column in the field study with PRD treatments achieved by applying different amounts of irrigation water to opposite sides of the plant. Air tem-

Field condition

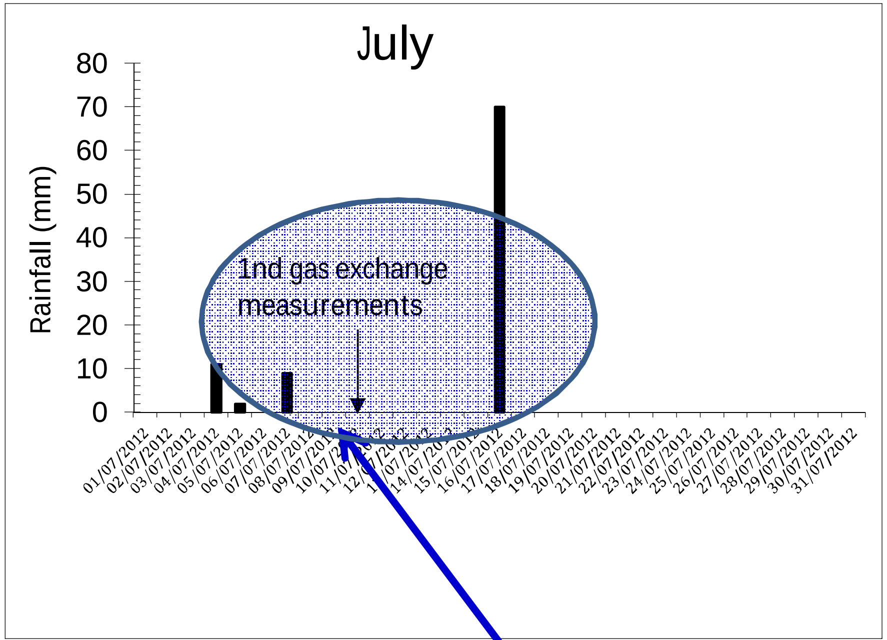
Table 2
Effect of five irrigation treatments on stem diameter and height of papaya in a field study. July (2012) and October (2012).

Treatment[a]	Sampling Time			
	July		October	
	Diameter (mm)	Height (m)	Diameter (mm)	Height (m)
RDI	115.91	3.48ab[z]	114.32	3.61
FI	110.52	3.31ab	115.35	3.41
NI-field	113.76	3.08c	113.87	3.65
PRD100	112.80	3.37ab	121.35	3.67
PRD70	117.85	3.57a	116.88	3.79
	ns[y]		ns	ns

[a] FI = full irrigation; NI-field = no irrigation after treatment initiation; PRD100 = partial root zone drying with 100% water replacement; PRD70 = partial root zone drying with 70% water replacement; RDI = regulated deficit irrigation with 70% water replacement.

[z] Mean values within a column followed by the same letter are not significantly different ($P = 0.05$) based on Tukey's multiple range test.

[y] Non-significant difference.



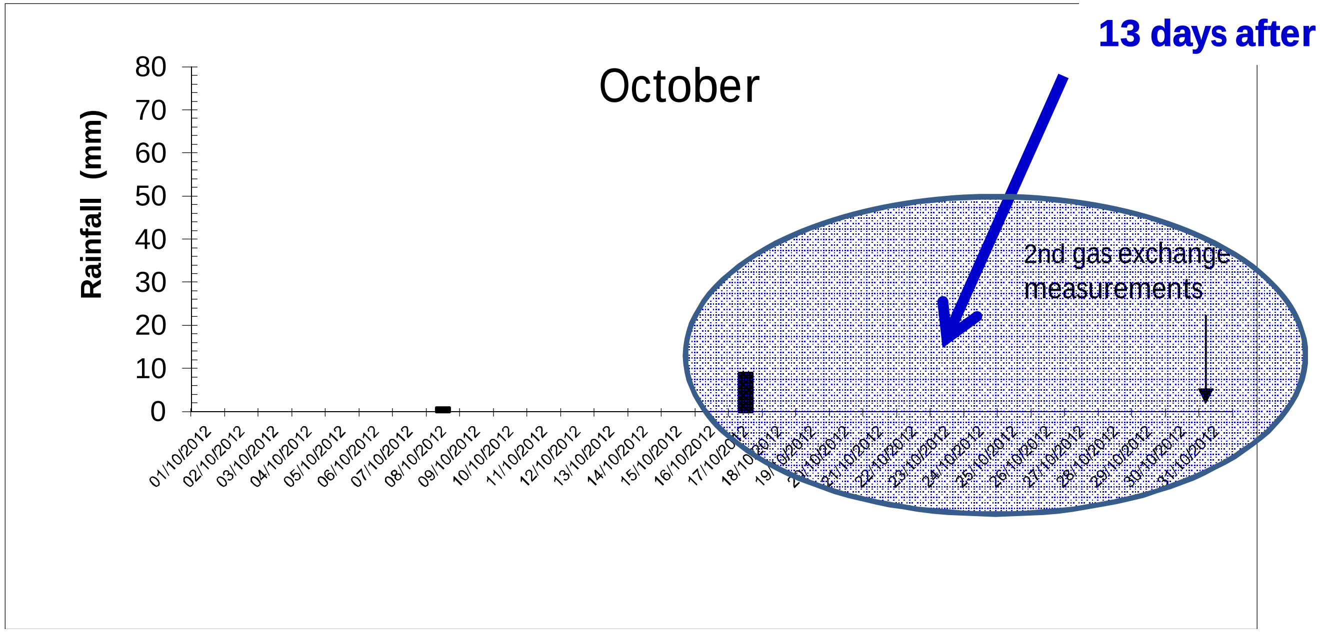
3 days after rainfall

Table 4
Effect of 5 irrigation treatments on photosynthesis (A), stomatal conductance (G_s) and transpiration (E) of papaya in a field study. July (2012) and October (2012).

Treatment[a]	Sampling	A (μmol m^{-2} s^{-1})	G_s (mol m^{-2} s^{-1})	E (mmol m^{-2} s^{-1})
RDI **70%**	July	14.8	0.19	4.3
FI	July	12.1	0.15	3.5
NI-field	July	13.2	0.21	4.4
PRD100	July	12.5	0.15	3.3
PRD70	July	12.7	0.18	4.0
		ns[y]	ns	Ns
RDI **70%**	October	9.5ab[z] ←	0.12ab ←	4.4ab ←
FI	October	10.8a ←	0.13a ←	5.5a ←
NI-field	October	6.5b	0.06c	3.2b
PRD100	October	9.3ab	0.11abc	4.6ab ←
PRD70	October	7.2b	0.08bc	3.4b

[a] FI = full irrigation; NI-field = no irrigation after treatment initiation; PRD100 = partial root zone drying with 100% water replacement; PRD70 = partial root zone drying with 70% water replacement; RDI = regulated deficit irrigation with 70% water replacement.
[z] Mean values within a column followed by the same letter are not significantly different ($P = 0.05$) based on Tukey's multiple range test.
[y] Non-significant difference.

13 days after rainfall



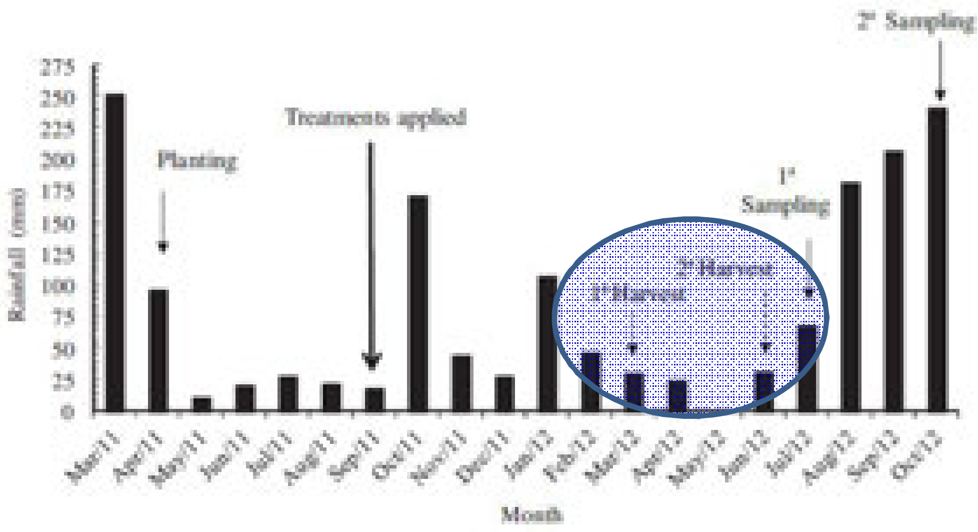


Fig. 2. Meteorological variables in a field study.

Table 3
Effect of 5 irrigation treatments on yield components and agronomic water use efficiency (AWUE) of papaya in a field study. March (2012) and June (2012).

Harvest	Treatment[a]	Number fruit plant^{-1}	Average weight (g FW fruit^{-1})	Yield (kg FW ha^{-1})	kg FW plant^{-1}	Irrigation + precipitation (L)	AWUE (kg FW fruit L^{-1})	AWUE (number fruit L^{-1})
March	FI	30b[z]	409ab	22,065ab	11.9b	2698	0.0044c	0.011c
March	NI-field	33ab	391b	23,991b	13.0ab	1025	0.0126a	0.032a
March	PRD100	38ab	436ab	31,290ab	16.9ab	2698	0.0063bc	0.014bc
March	PRD70	41a	437a	33,827a	18.3a	2189	0.0084b	0.019b
March	RDI	39ab	430ab	31,117ab	16.8ab	2189	0.0077b	0.018b
			$P = 0.10$					
June	FI	21a	244ab	9620ab	5.2ab	3755	0.0014	0.006
June	NI-field	6b	191b	2651b	1.4b	1107	0.0013	0.006
June	PRD100	26a	309a	14,881	8.0a	3755	0.0021	0.007
June	PRD70	19a	286a	10,390a	5.6ab	2949	0.0019	0.006
June	RDI	20a	282a	11,145a	6.0ab	2949	0.0020	0.007
							ns[y]	ns

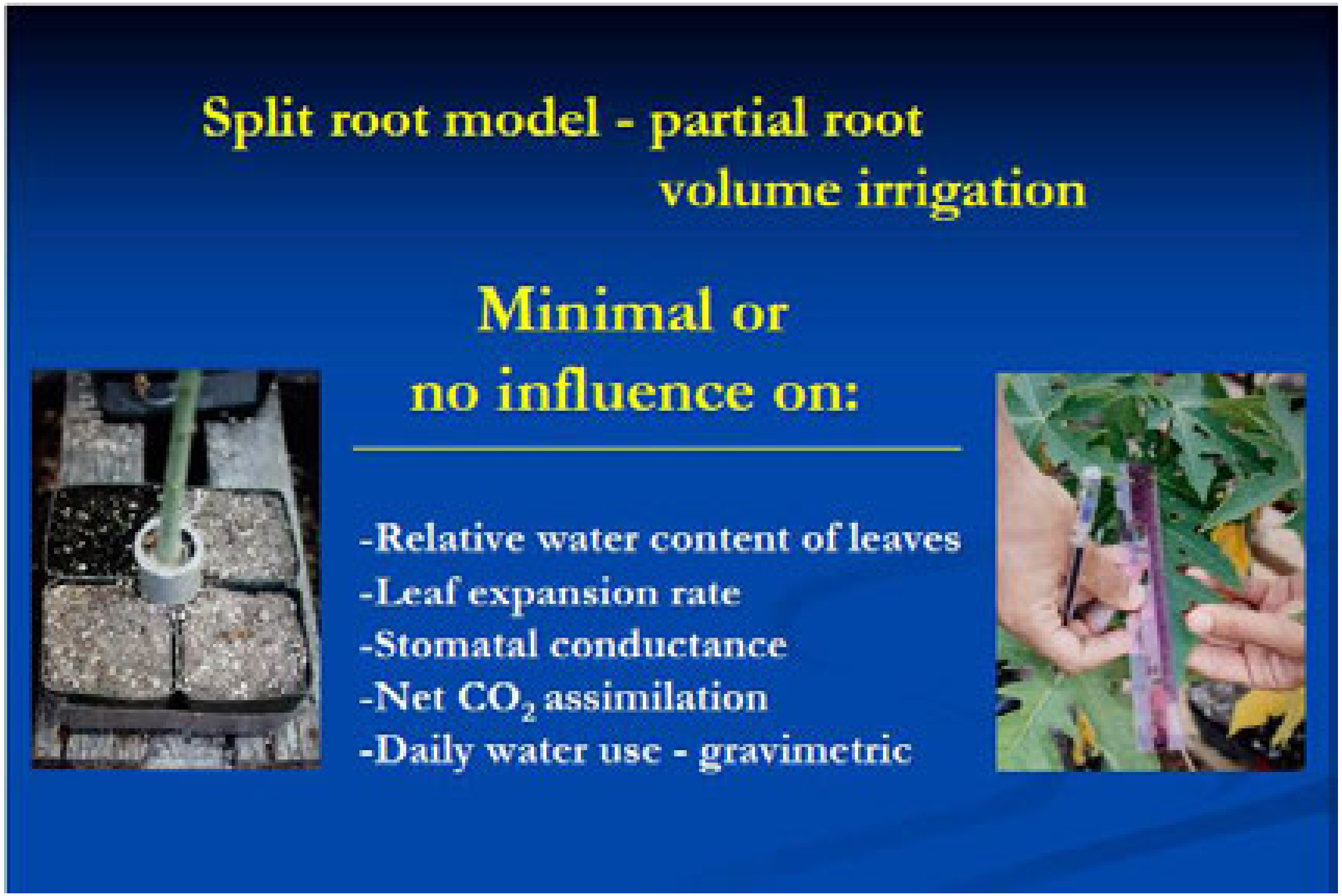
[a] FI = full irrigation; NI-field = no irrigation after treatment initiation; PRD100 = partial root zone drying with 100% water replacement; PRD70 = partial root zone drying with 70% water replacement; RDI = regulated deficit irrigation with 70% water replacement.
[z] Mean values within a column followed by the same letter are not significantly different ($P = 0.05$) based on Tukey's multiple range test.
[y] Non-significant difference.

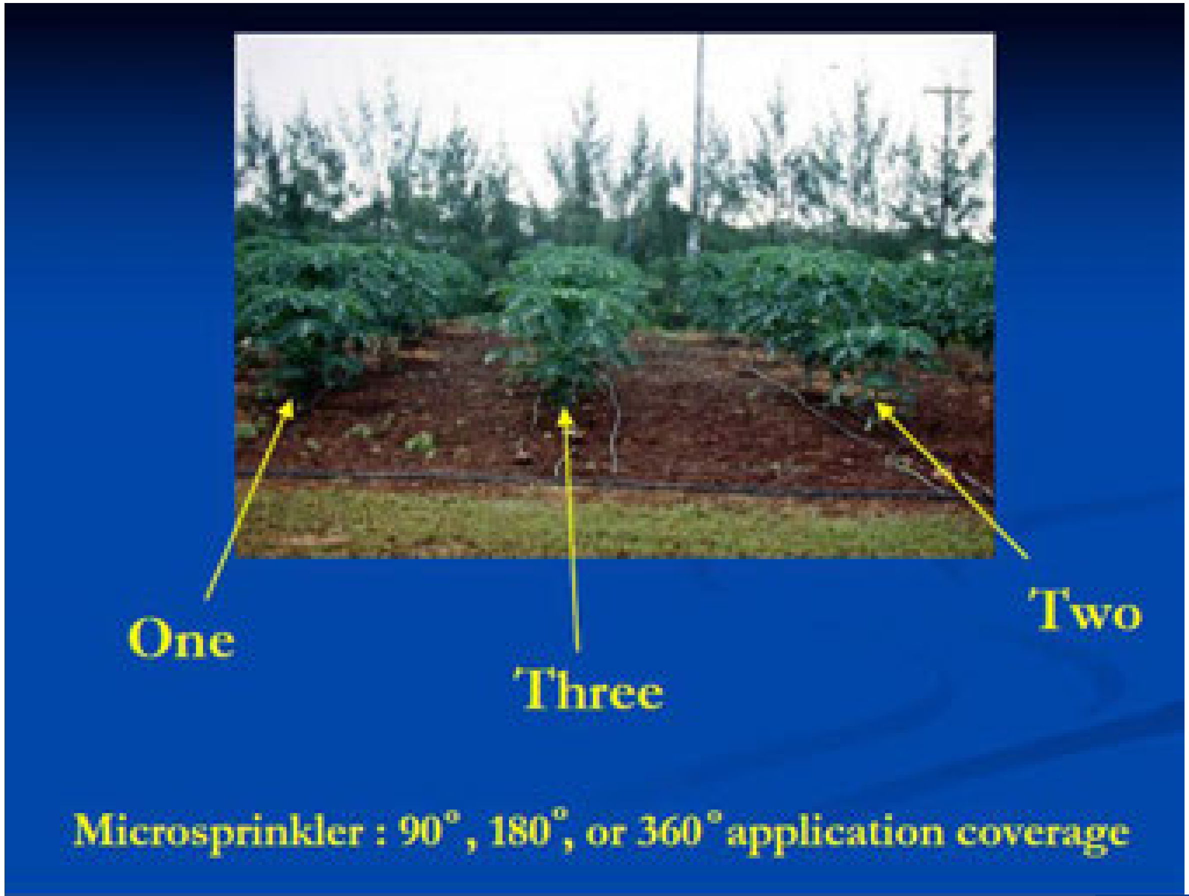
5. Conclusion

While there was evidence of non-hydraulic signals inducing stomatal closure in the PRD treatments compared to RDI in greenhouse studies, these effects were insufficient to alter dry matter partitioning, biomass, or yield components since there were no significant differences between PRD and RDI at either a 30% or 50% water deficit. A 50% water deficit in the greenhouse study for the PRD and RDI treatments was sufficient to significantly reduce biomass and dry matter partitioning compared to the FI treatment. In the field study, a 30% water deficit in both PRD70 and RDI treatments did not significantly reduce vegetative growth or yield components, compared to FI. It appears that papaya can tolerate moderate water deficits without a significant reduction in yield components indicating that <100% ET irrigation replacement may be scheduled but there is little or no difference between PRD and RDI. Further research will be needed to verify that moderate soil water deficits do not reduce quality.

Dr. Thomas Marler
University of Guam
Guam

Western Pacific Tropical Research Center
Research for Guam's Future



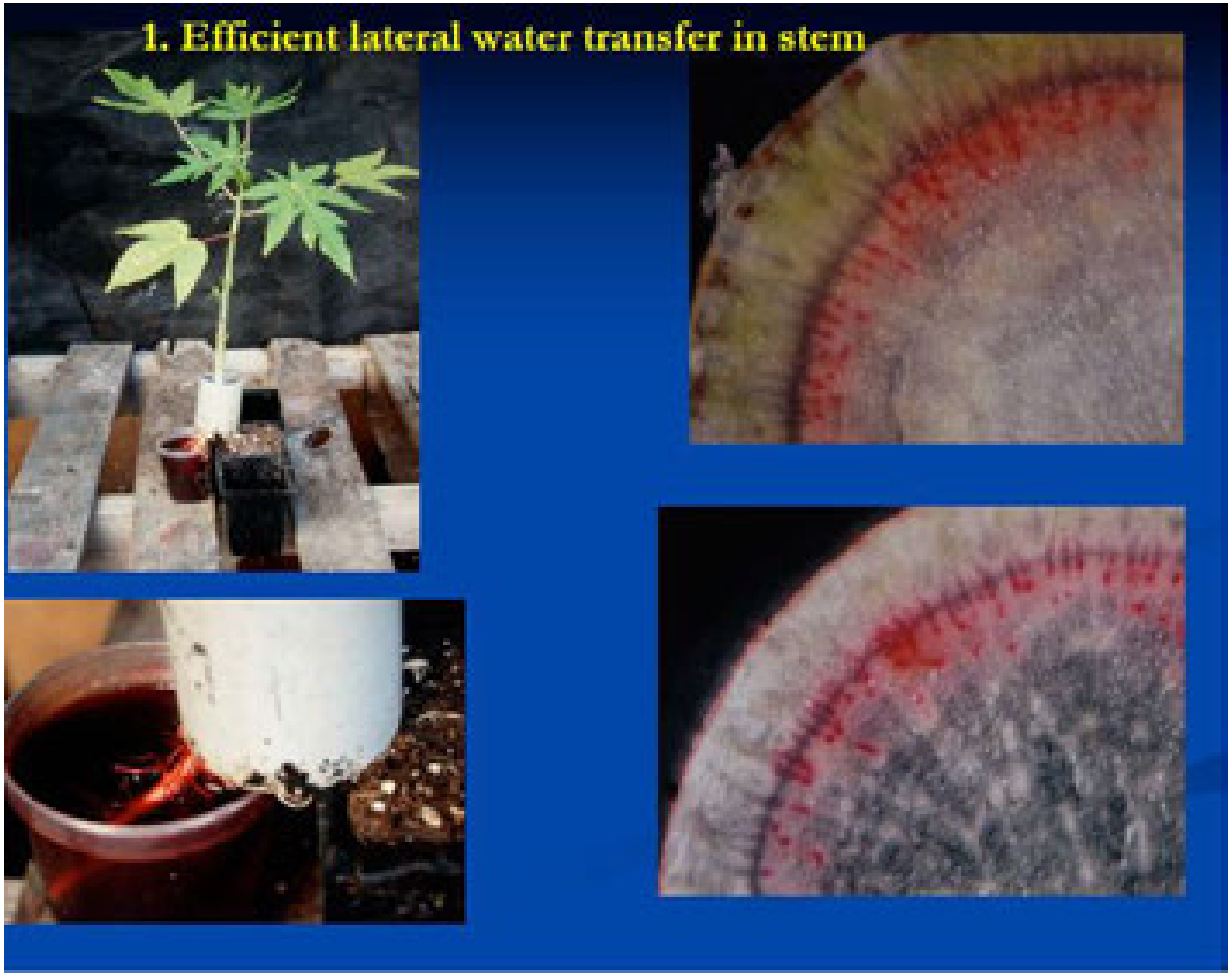


No influence on:

- Growth - height or stem diameter
- Date of first flowers
- Height of first fruit
- Yield

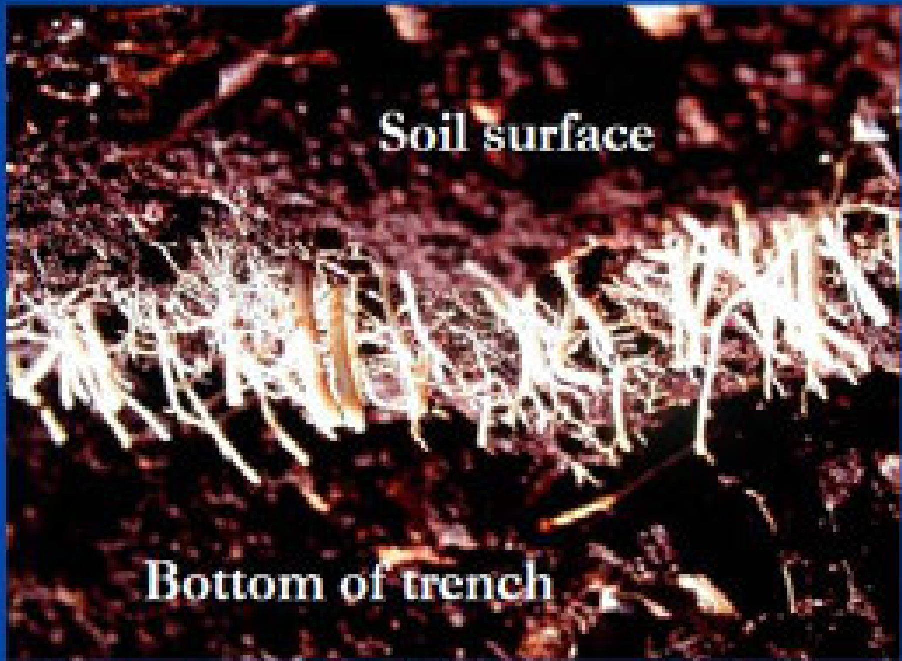
Papaya attributes that allow for this:

1. Efficient lateral transfer of water in stem
2. Rapid root proliferation in wet zones
3. Hydraulic redistribution into dry zones



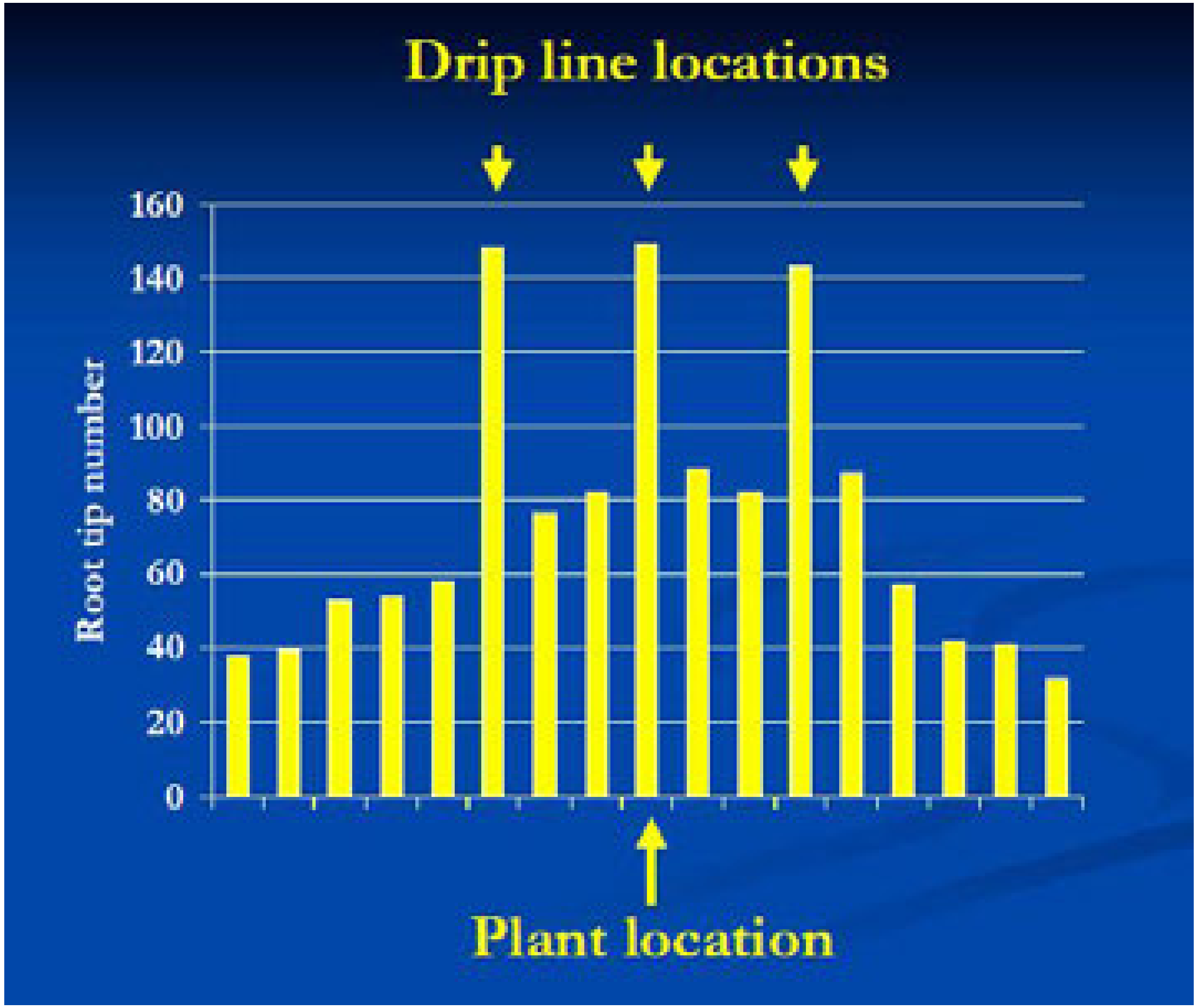

20 cm above-
100%
10 cm above-
80%
6 cm above-
50%

Papaya attributes that allow for this:
2. Rapid root proliferation in wet zones



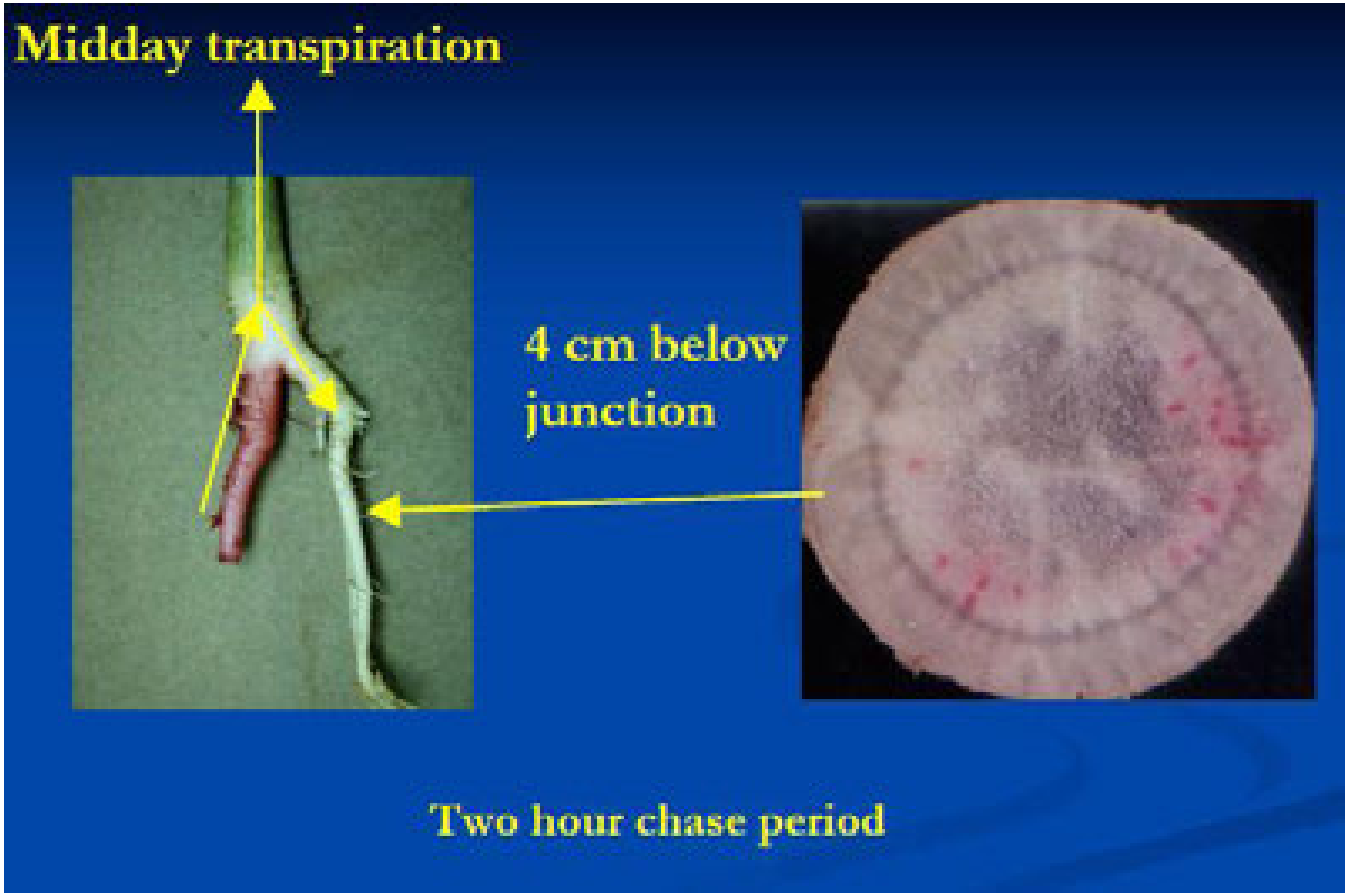
-Trench profile

-Cores



Drip line locations
160
140
120
100
80
60
40
20
0
Root tip number
Plant location

3. Hydraulic redistribution into dry zones



Water Transfer in a Papaya-Corn Culture System

Proc. Third IS on Papaya
Eds.: N. Chomchalow et al.
Acta Hort. 1022, ISHS 2014

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Abstract

'Tainung 2' and 'Sunrise' papaya seedlings were grown in split-root containers. 'Honey Jean 3' sweet corn seeds were planted in one of the two containers that comprised each split-root papaya system. Following establishment of the corn seedlings, the papaya-corn systems were subjected to one of three treatments: 1) both halves of the papaya roots were well-watered (control); 2) both halves of the papaya roots received no water; (3) the papaya root half without the corn seedling was watered but the half with the corn seedling received no water. Pre-dawn leaf relative water content (RWC) and mid-morning stomatal conductance of corn leaves were the response variables used to quantify drought stress. Stomatal conductance reached zero by day 10, when RWC of treatment 2 plants was less than 50% and that of treatment 3 plants was 80%. At this stage, half of the remaining replications in treatment 3 were treated by cutting the connection between the roots in the dry compartment and the base of the papaya stem. This procedure relieved competition between the two species, but also eliminated the watered half of the papaya roots as a possible source of water for the corn plants. Leaf RWC of the corn plants relieved of papaya root competition declined to below that of corn plants within intact treatment 3 papaya split root systems. These results indicate hydraulic redistribution occurred from papaya roots in the watered pots to the corn plants. Water redistribution within papaya plants may have impacts on hydrologic processes, and should be considered when scaling fluxes to the orchard level.

FI. We hypothesized that the difference observed in physiological response to PRD and RDI treatments between the papaya grown in the greenhouse and field may be related to the different volumes of soil explored by the root system. The physiological response of papaya to PRD and RDI was more affected in greenhouse-grown than field-grown papaya because in the greenhouse study, the roots are limited to the volume of the pot. In addition, in field conditions rainfall can increase water availability in the soil and the roots have a greater volume of soil to explore. Thus, environmental variables such as VPD and PAR can more severely affect the gas exchange and growth of plants grown in the greenhouse than plants grown under field condition. In addition, PRD and RDI can increase stomatal sensitivity to VPD (Collins et al., 2010).

Collins, M.J., Fuentes, S., Barlow, W.R., 2010. Partial rootzone drying and deficit irrigation increase stomatal sensitivity to vapour pressure deficit in anisohydric grapevines. Funct. Plant Biol. 37, 128–138.

Flooding

Papaya is considered a species sensitive to low oxygen availability in the soil (hypoxia), which is commonly caused by waterlogging (Ogden et al., 1981; Malo and Campbell, 1986)

Reduced oxygen can occur as a result of tropical storms that saturate the soil for several days, flood irrigation, as well as micro-irrigation practices that create microenvironments of reduced soil oxygen

A completely flooded soil can cause **death to papaya plants in 2 d** (Wolf and Lynch, 1940; Khondaker and Ozawa, 2007) **or 3 to 4 d** (Samson, 1980)

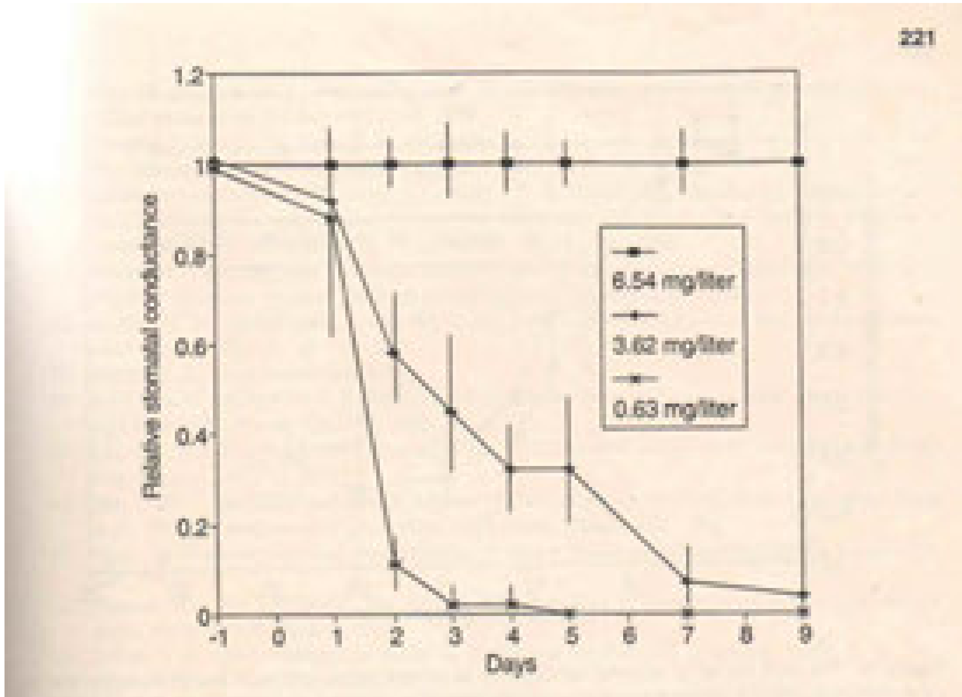

Figure 11 The time course of stomatal conductance of papaya leaves relative to that of control plants (6.54 mg/liter) as influenced by dissolved oxygen concentration in the nutrient solution. Data were standardized as a fraction of control. (Marler, T. E., unpublished data, 1990.)

Khondaker and Ozawa (2007) constructed chambers that controlled soil gas composition at ambient (20%), 18% and 11% oxygen; under soil oxygen at and below 18%, *A*, chlorophyll content, large and small roots, and shoot dry matter were all decreased

Papaya Plant Growth as Affected by Soil Air Oxygen Deficiency

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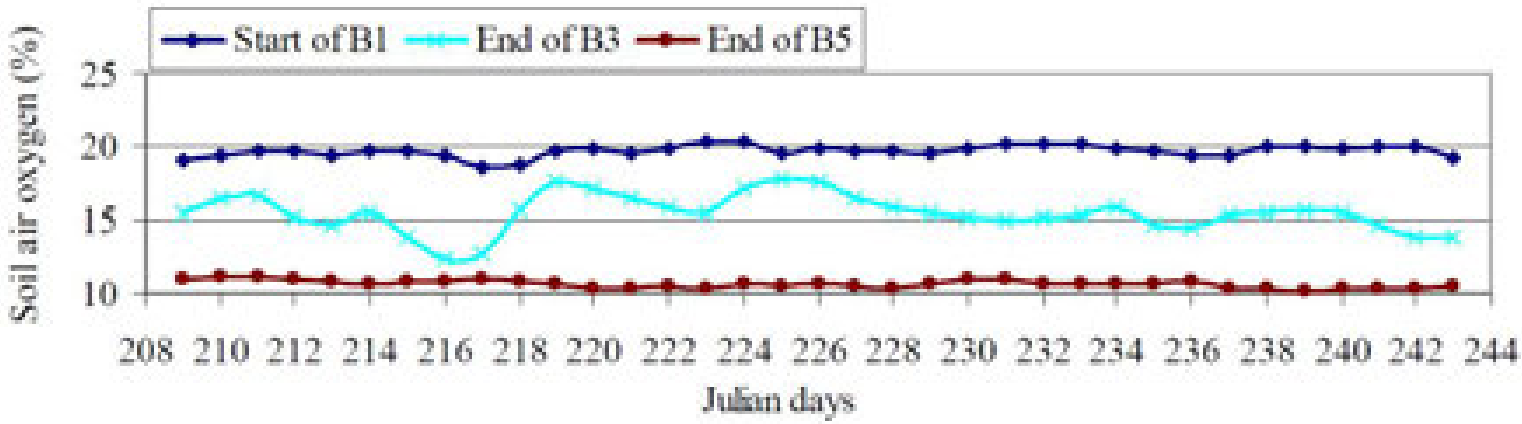
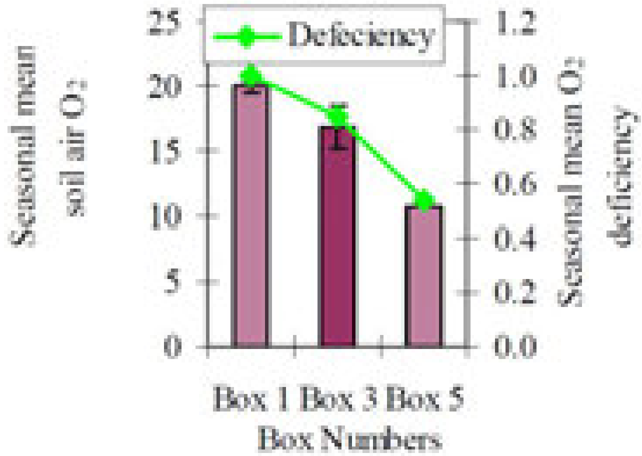
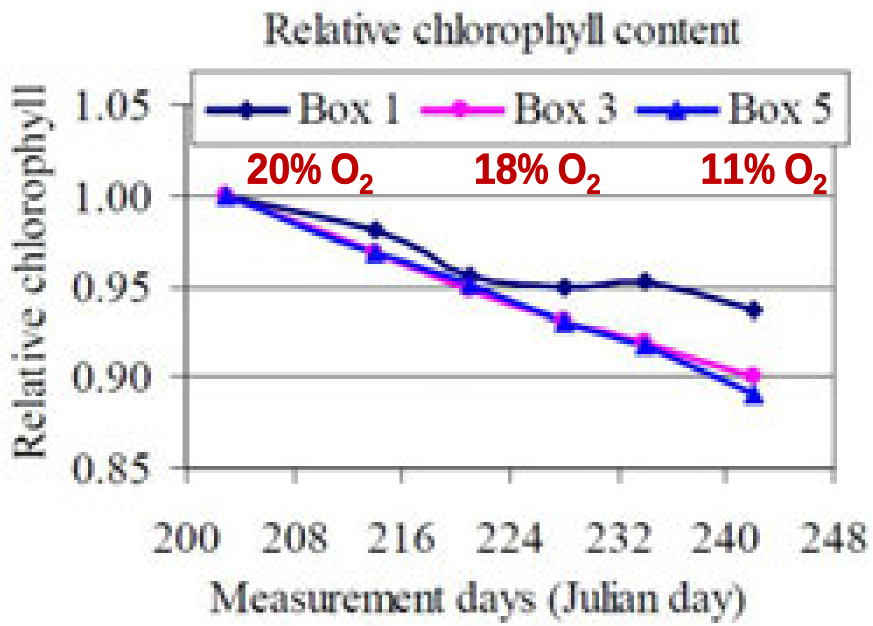
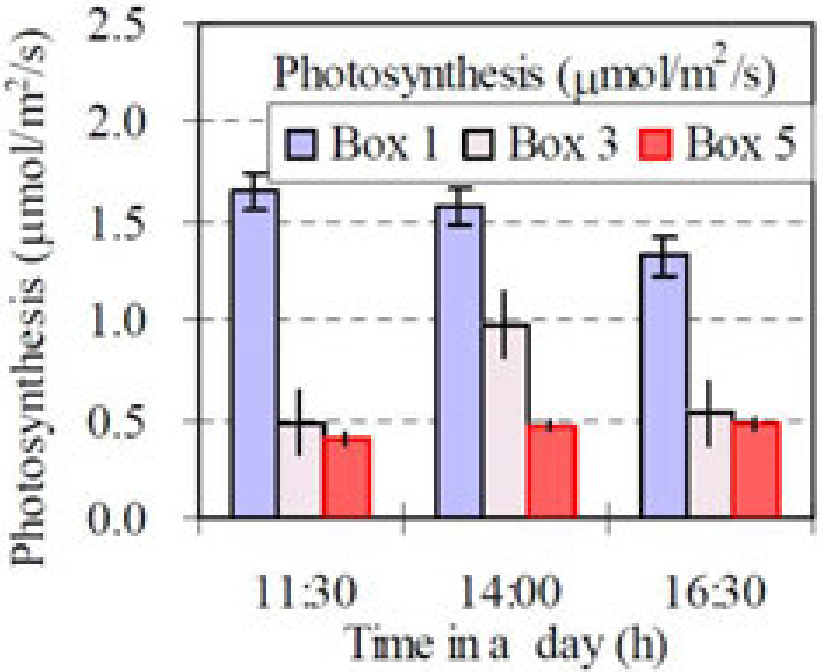
Proc. 1st IS on Papaya
R.E. Paull
IS 2007

20% O_2 **18% O_2** **11% O_2**

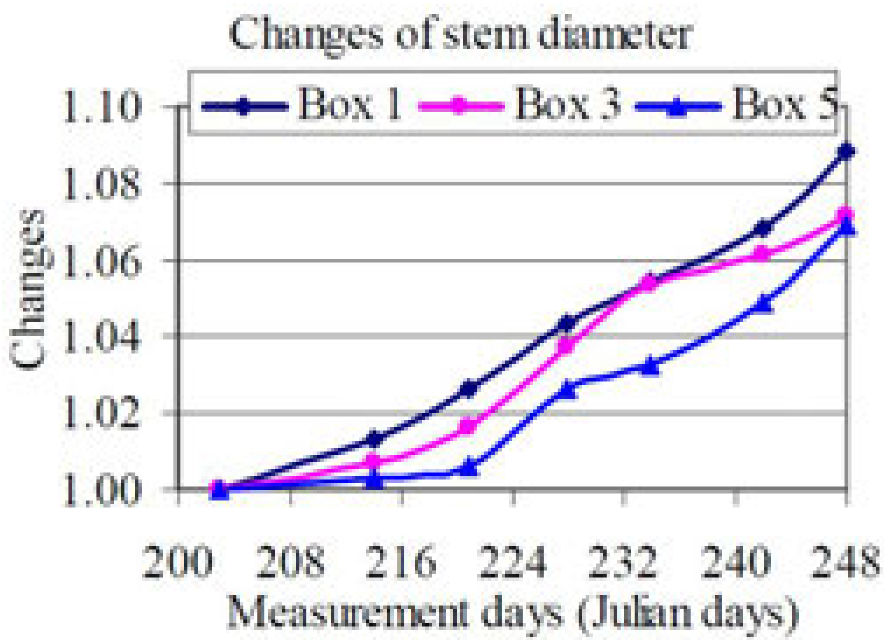


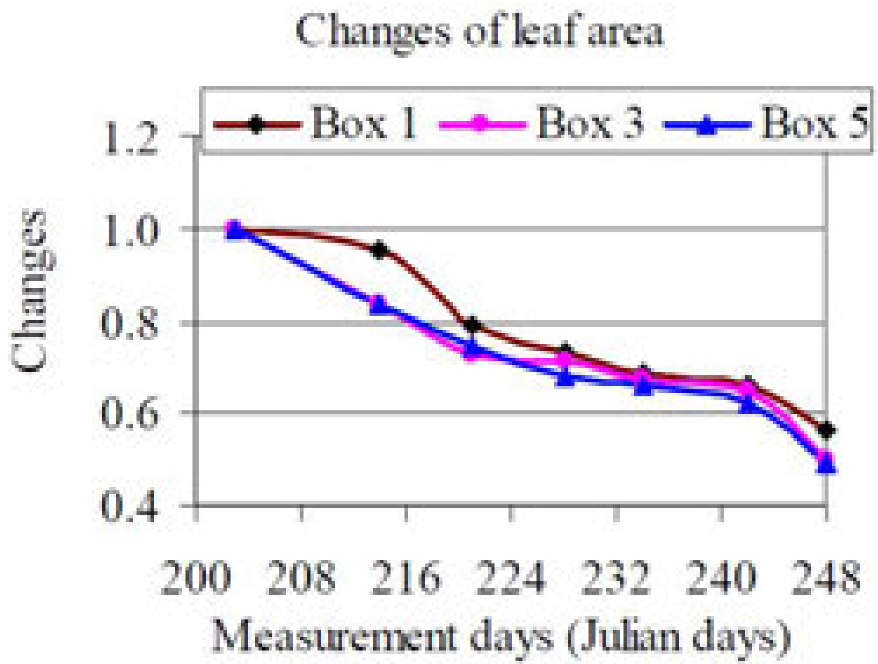


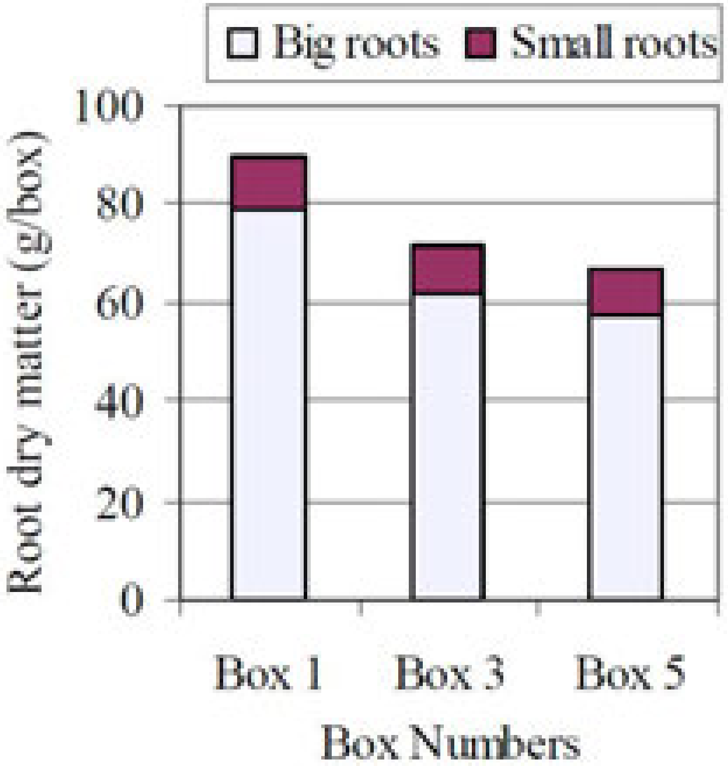

Relative chlorophyll content
Box 1
Box 3
Box 5
20% O2
18% O2
11% O2
Relative chlorophyll
1.05
1.00
0.95
0.90
0.85
200
208
216
224
232
240
248
Measurement days (Julian day)

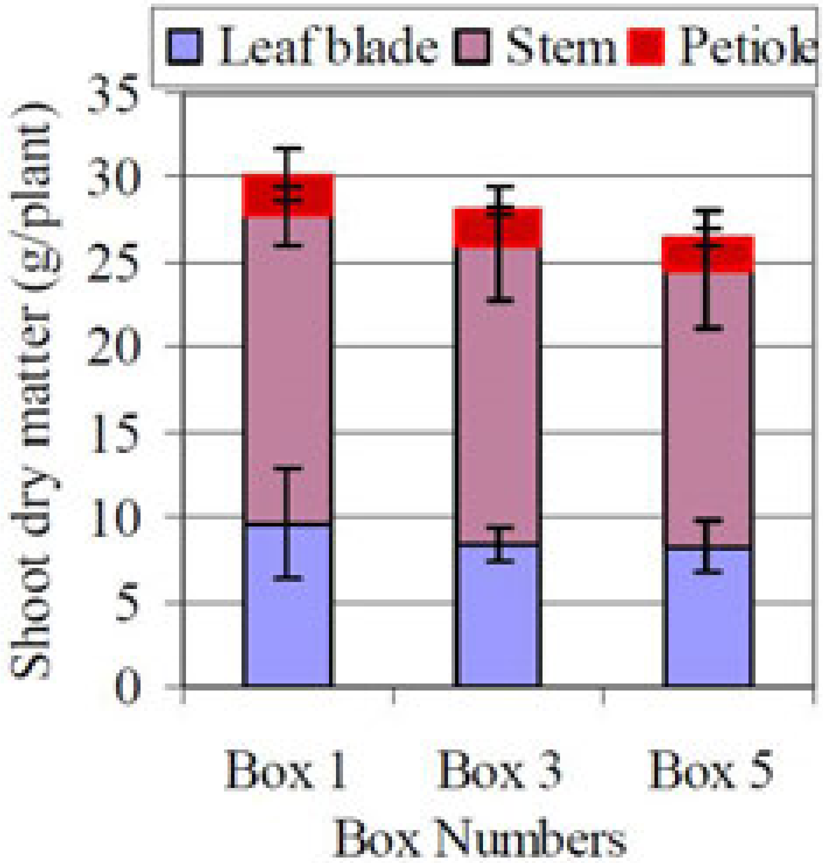

Photosynthesis (μmol/m2/s)
Box 1
Box 3
Box 5
Photosynthesis (μmol/m2/s)
2.5
2.0
1.5
1.0
0.5
0.0
11:30
14:00
16:30
Time in a day (h)

Box 1: 20% O_2
Box 2: 18% O_2
Box 3: 11% O_2






Big roots
Small roots
Root dry matter (g/box)
100
80
60
40
20
0
Box 1
Box 3
Box 5
Box Numbers

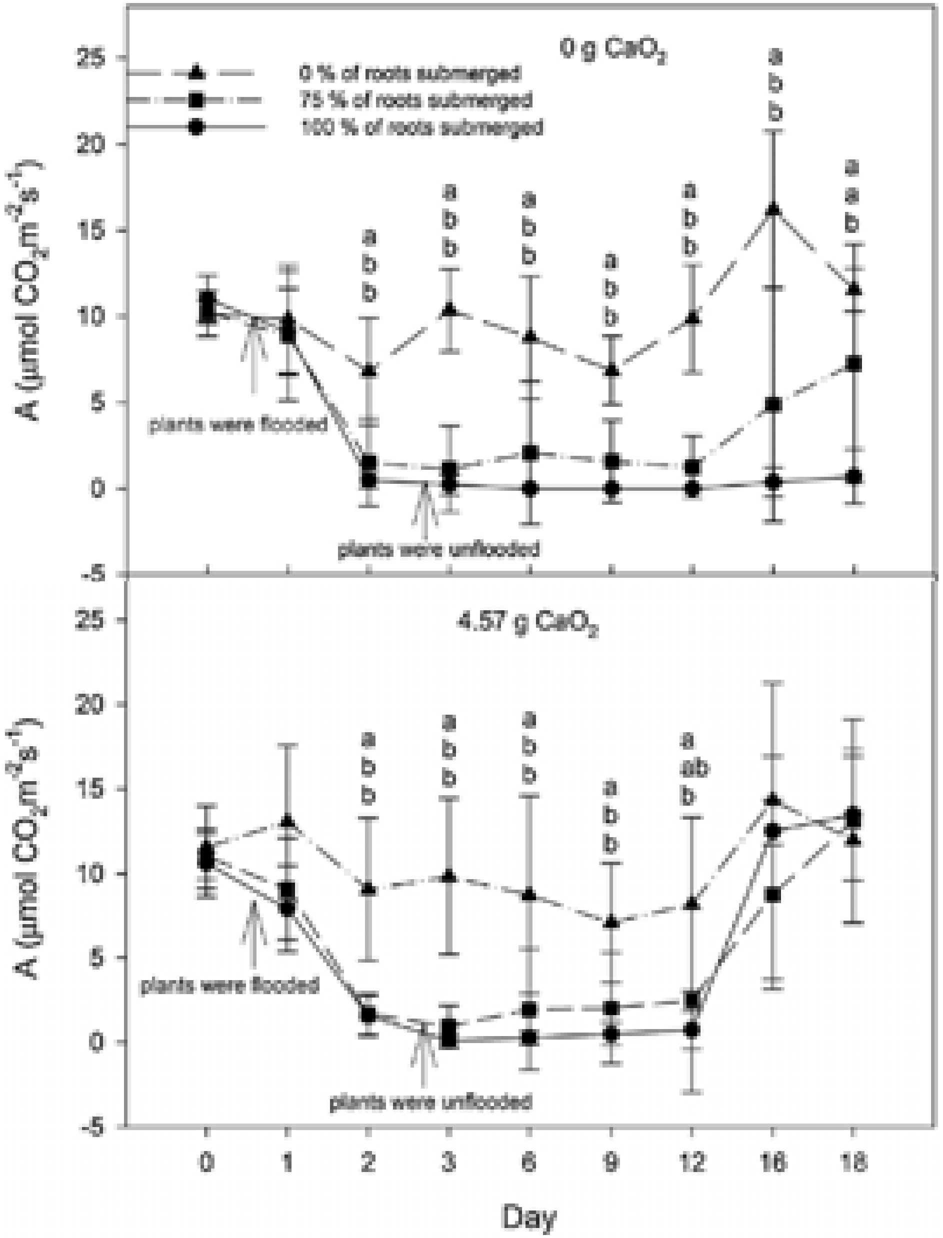

Leaf blade
Stem
Petiole
Shoot dry matter (g/plant)
35
30
25
20
15
10
5
0
Box 1
Box 3
Box 5
Box Numbers

Papaya, considered sensitive to hypoxia, responds with accentuated senescence (chlorotic leaves), leaf fall and does not recover after hypoxic conditions are removed (Marler et al., 1994).

These studies indicate that papaya is sensitive to small reductions in soil oxygen content and it is likely that micro-irrigation saturation of a small portion of the soil is having some negative effects. Consequently, a welldrained soil is essential for high productivity.

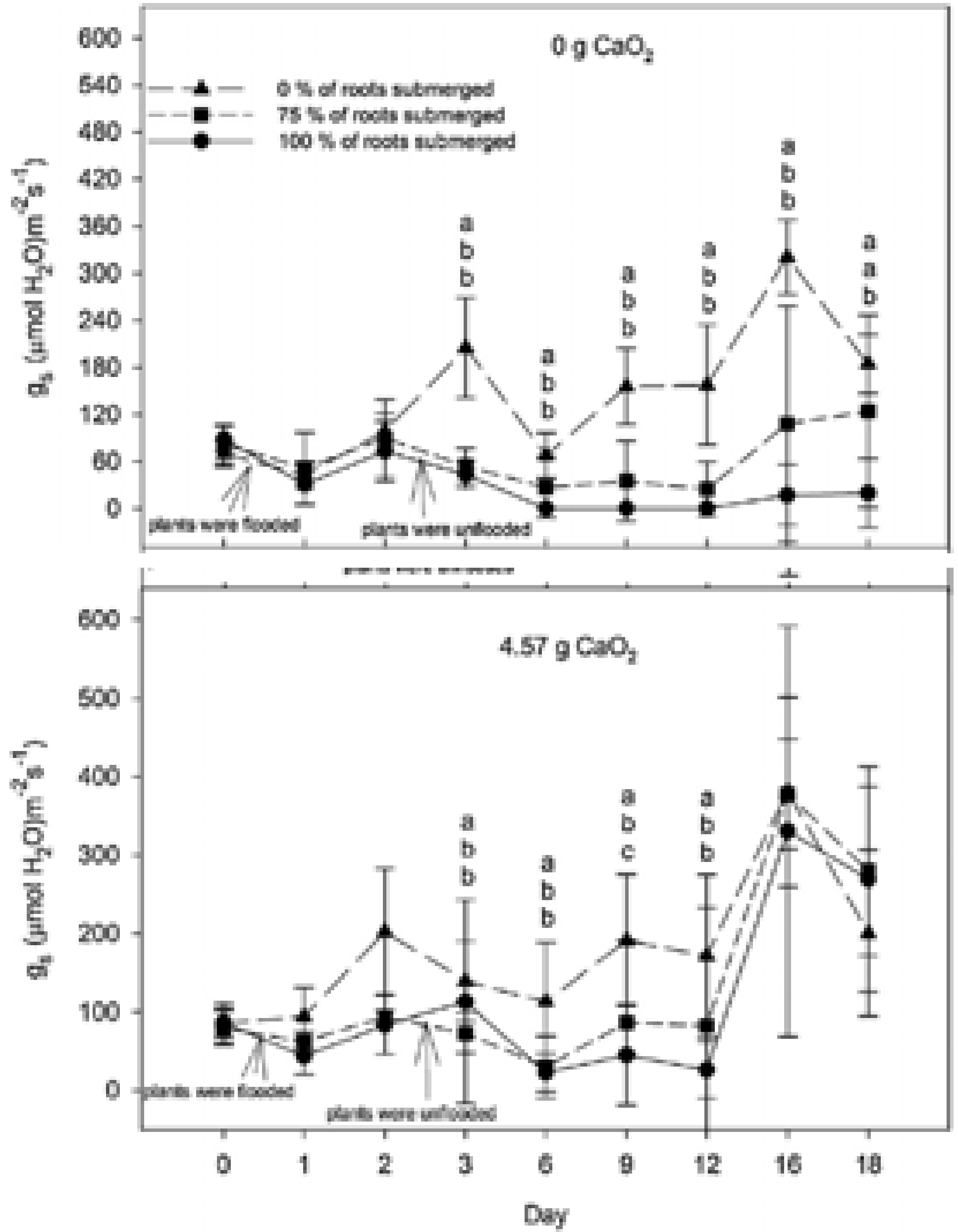
	100% of roots submerged	
	Dissolved O_2 concentration ($mg\,l^{-1}$)	
Treatment	Day 1	Day 2
0 g CaO_2	3.63 ± 0.92b	4.38 ± 0.89b
2.28 g CaO_2	7.00 ± 0.76a	5.38 ± 1.70ba
4.57 g CaO_2	8.03 ± 1.09a	7.19 ± 1.50a

et al., 2009a). Hydrogen peroxide decomposes in the soil, releasing O_2 which is needed for aerobic metabolism in the roots (Gil et al., 2009a,b). When H_2O_2 comes in contact with water, it reacts to give off 0.5 mol of O_2 per mole H_2O_2 as shown in the equation $H_2O_2 + H_2O \rightarrow 0.5O_2 + 2H_2O$ (Gil et al., 2009a). In soil, solid oxygen compounds (i.e., CaO_2, MgO_2) breakdown to H_2O_2 which then provides oxygen to the rhizosphere (Liu and Porterfield, 2014).

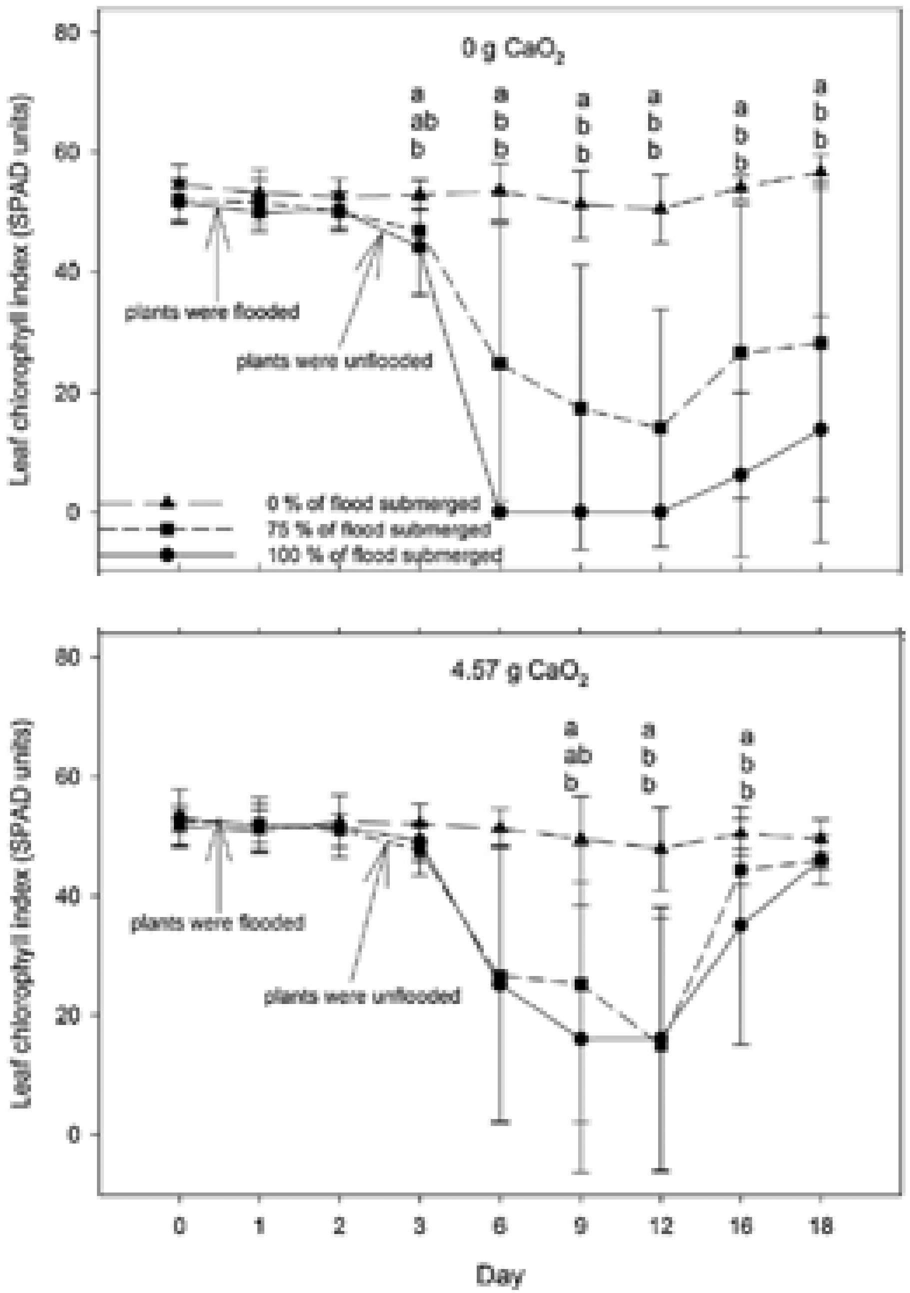


2.5-l plastic bucket

pots (Thani, 2016). Calculations were then made to account for the smaller pot size in the present experiment. CaO_2 was applied evenly to the soil surface a few minutes prior to beginning the flooding treatments. Treatments were arranged in a randomized complete



0 g CaO2
0 % of roots submerged
75 % of roots submerged
100 % of roots submerged
gs (µmol H2O)m-2s-1)
plants were flooded
plants were unflooded
4.57 g CaO2
Day



0 g CaO_2
4.57 g CaO_2
Leaf chlorophyll index (SPAD units)
plants were flooded
plants were unflooded
0 % of flood submerged
75 % of flood submerged
100 % of flood submerged
Day

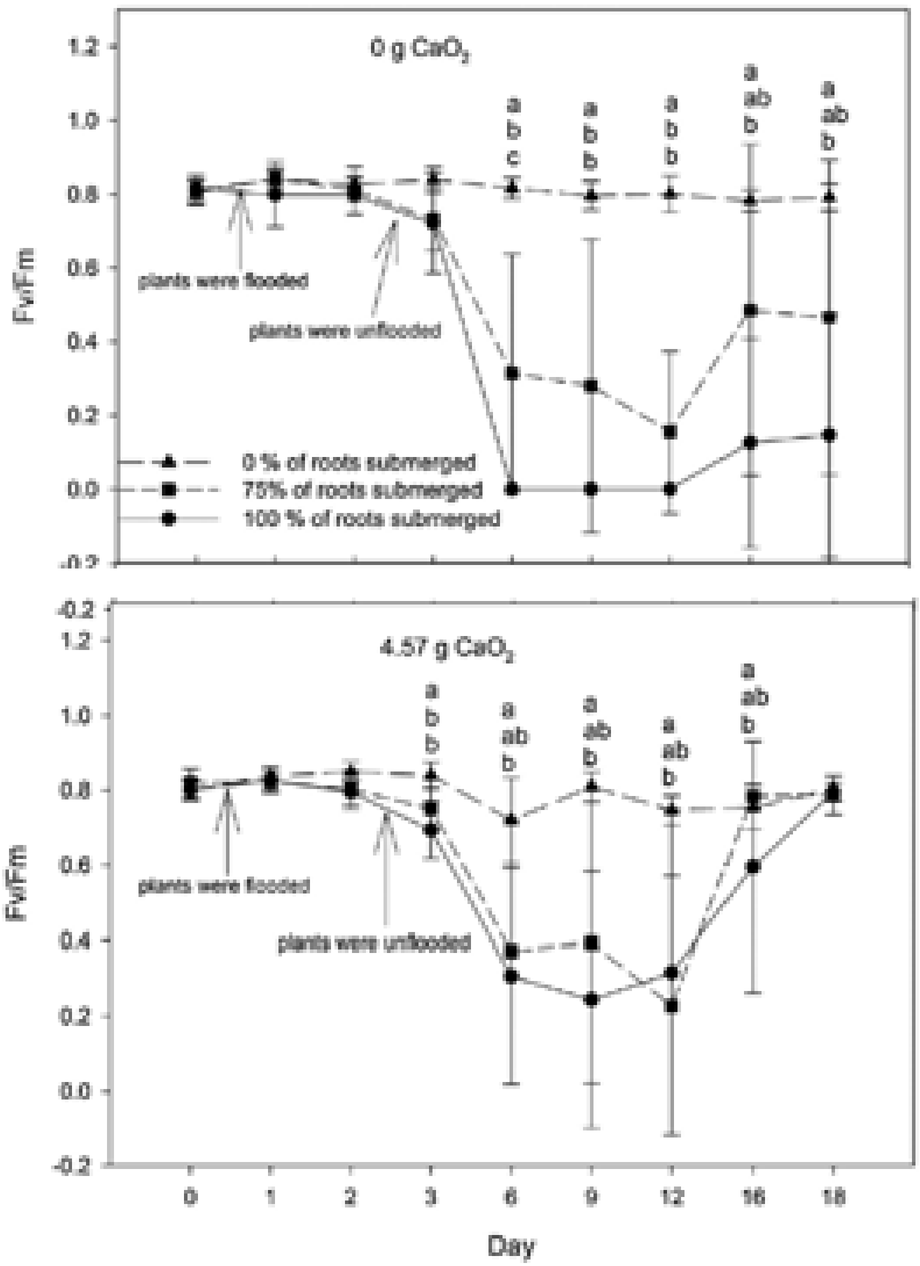
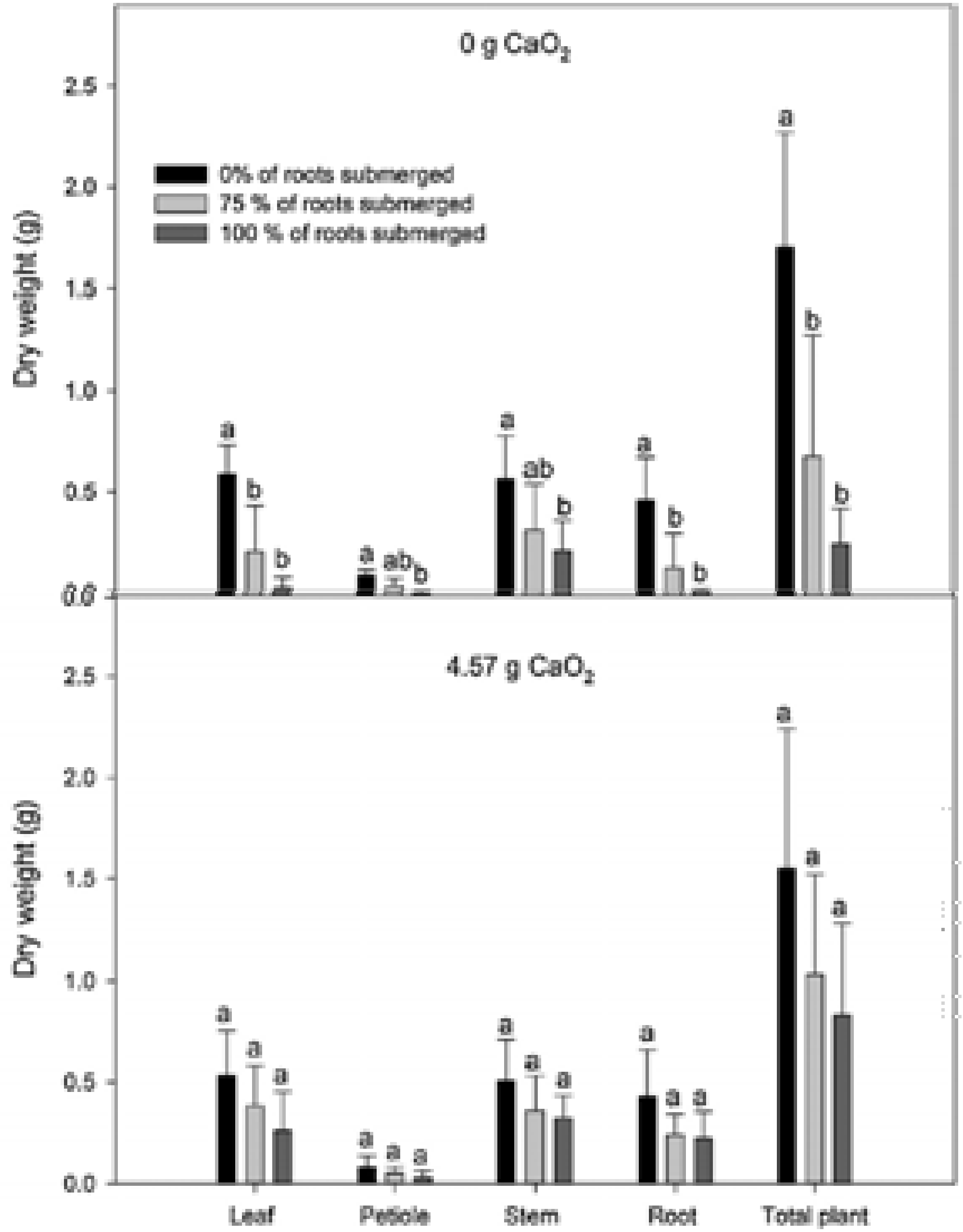

0 g CaO2
4.57 g CaO2
Fv/Fm
plants were flooded
plants were unflooded
0 % of roots submerged
75% of roots submerged
100 % of roots submerged
Day

Table 2
Survival of papaya (*Carica papaya* L.) seedlings in Krome very gravelly loam soil with 0%, ~75%, or 100% of roots submerged in H_2O with different concentrations of CaO_2 added to the soil (Experiment 1).

CaO_2 application rate (g)	Amount of roots submerged (%)		
	0	~75	100
	Plant survival (%)		
0	100	60	40
2.28	100	80	80
4.57	100	100	100


0 g CaO_2
4.57 g CaO_2
0% of roots submerged
75 % of roots submerged
100 % of roots submerged
Dry weight (g)
0.0
0.5
1.0
1.5
2.0
2.5
Leaf
Petiole
Stem
Root
Total plant

Salinity

Papaya seed germination is inhibited by very low levels of salinity (Kottenmeier et al., 1983), yet seedling growth can be stimulated by 1/10 seawater salinity levels (8 mS cm^{-1}) when compared to a Hoagland's nutrient solution control (Kottenmeier et al., 1983)

Maas (1993), however, classified papaya production as moderately sensitive with salinity effects at 3 mS cm^{-1}

Similarly Elder et al. (2000) found that moderately saline water (1.4 to 4 mS cm^{-1}) applied in trickle or under-tree mini-sprinkler irrigation had no adverse affect on productivity but when overhead applied, there was leaf damage and reduced growth.

seawater:
3.5% (35 g/L, or 599 mM)
50-80 mS cm^{-1}
Hoagland solution:
2.7 mS cm^{-1}

1 mS cm^{-1} = 1 dS m^{-1}

3200 ppm (mg L^{-1}) de NaCl equivale a 5 dS m^{-1}
3.2 g NaCl 1Litro de água = 5 dS m^{-1}

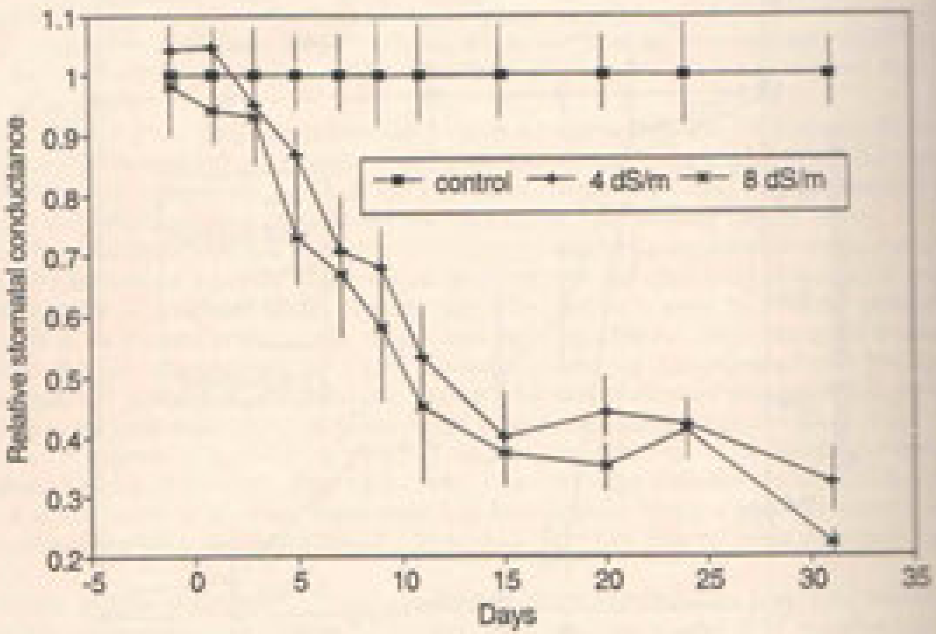


Figure 12 The time course of stomatal conductance of papaya leaves relative to that of control plants as influenced by salinity of irrigation water. Data were standardized as a fraction of control (Marler, T. E. unpublished data, 1990.)

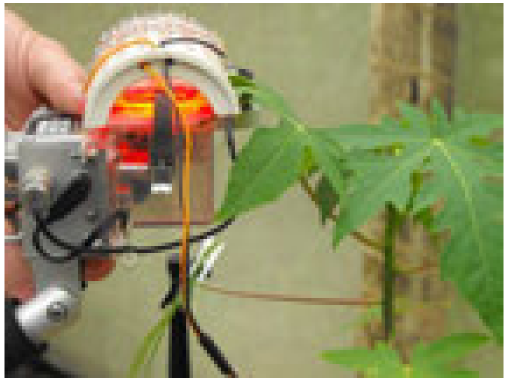
The experiment was conducted in a greenhouse between March and October 2010, at UENF, in Campos dos Goytacazes, RJ

2 genotypes: Golden and UENF/Caliman

100L pots

EC 1; 1.6; 2.2; 2.8; and 3.4 dS m^{-1}

96 to 126 Days after transplanting



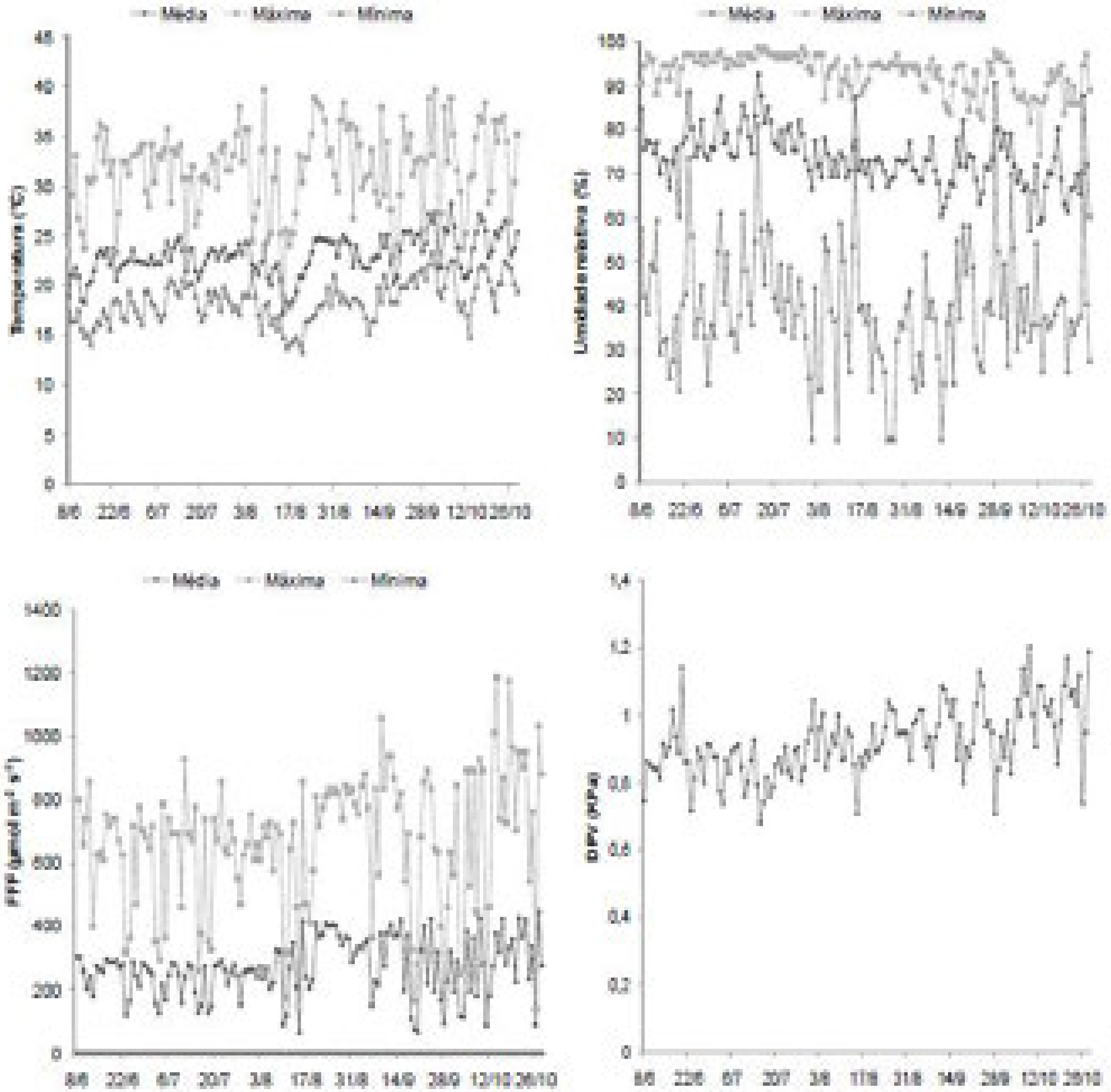
* Control.

The experiment was conducted in a greenhouse between March and October 2010, at UENF, in Campos dos Goytacazes, RJ

2 genotypes: Golden and UENF/Caliman

100L pots

EC 1; 1.6; 2.2; 2.8; and 3.4 dS m^{-1}



* Control.

The experiment was conducted in a greenhouse between March and October 2010, at UENF, in Campos dos Goytacazes, RJ

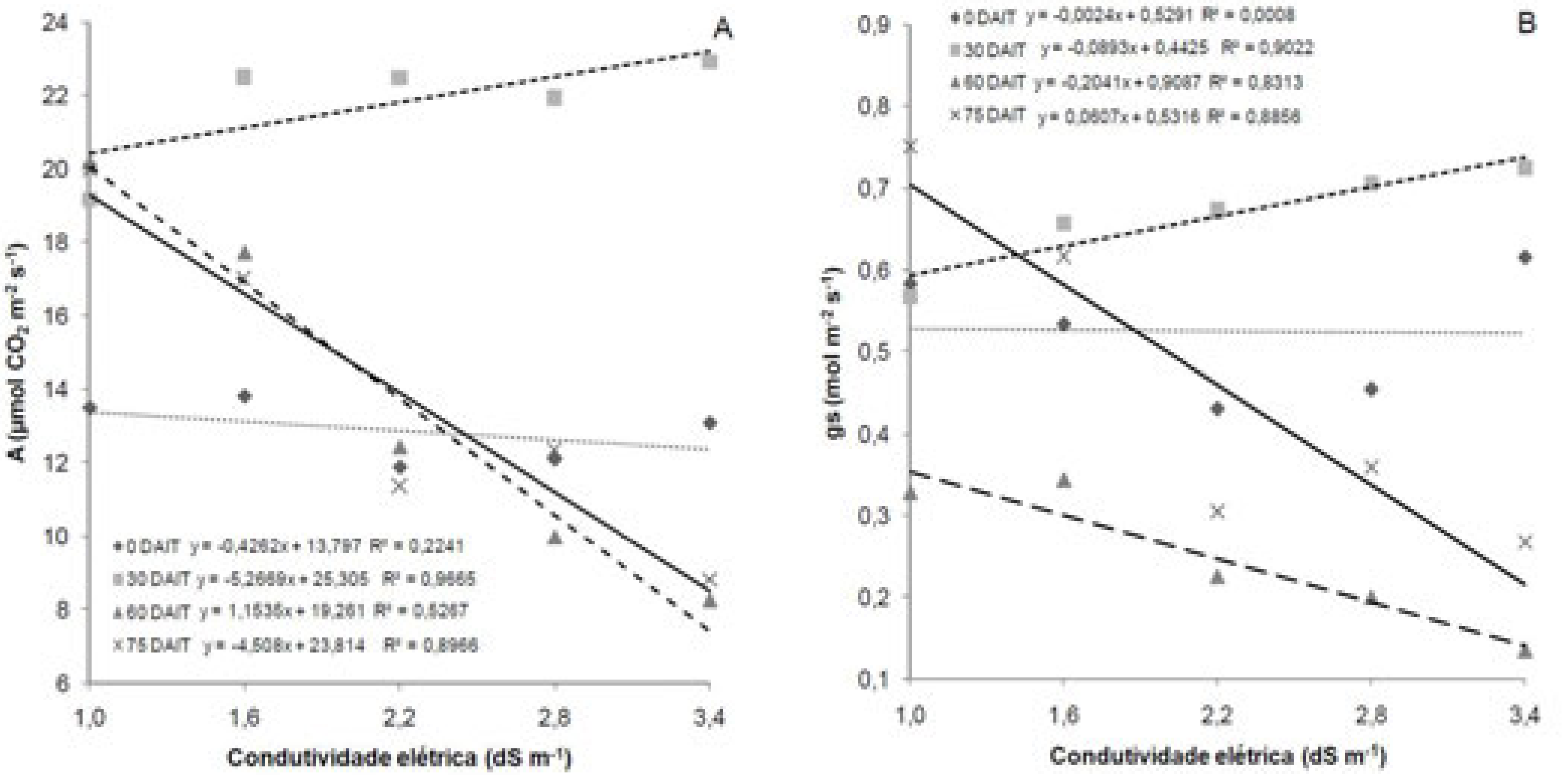
2 genotypes: Golden and UENF/Caliman

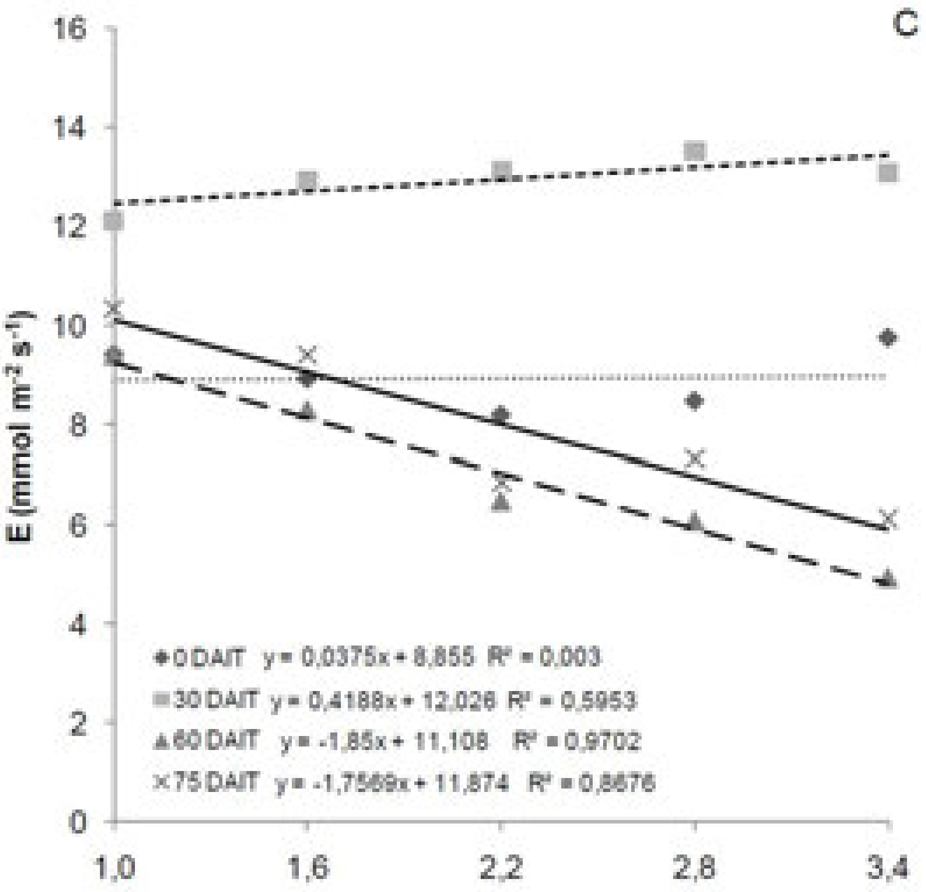
100L pots

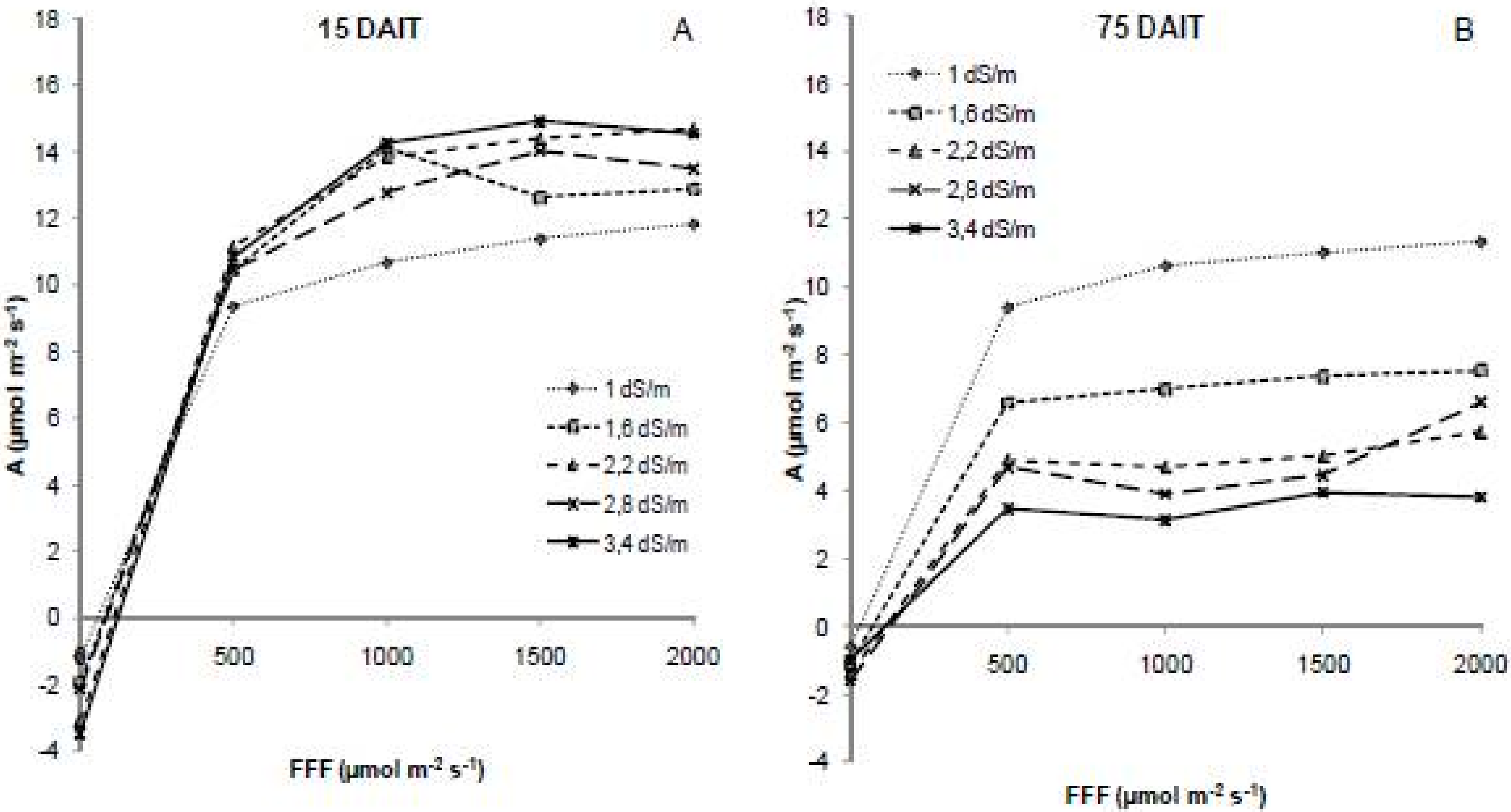
EC 1; 1.6; 2.2; 2.8; and 3.4 dS m^{-1}

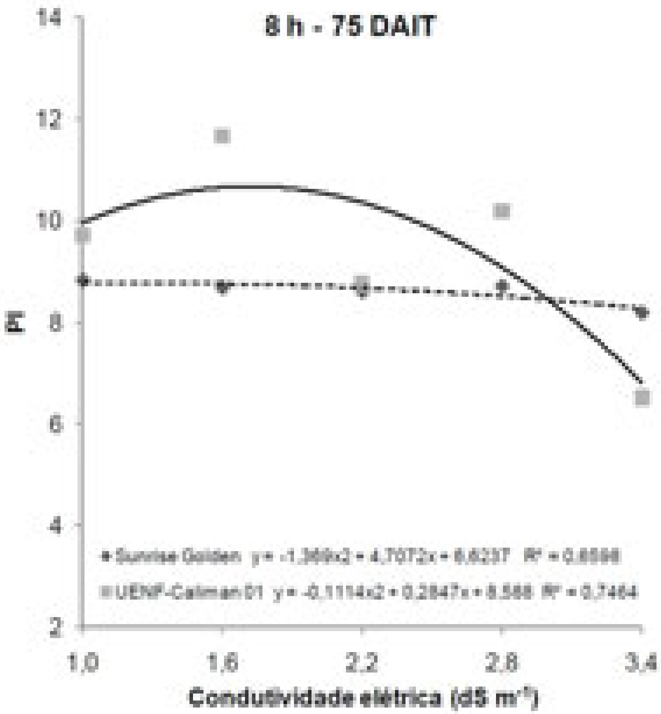
	Fertilizers (g)	Treat. 1 x 0.5	Treat. 2* x 1	Treat. 3 x 1.5	Treat. 4 x 2	Treat. 5 x 2.5
Solution A	Urea	23.7	47.5	71.3	95.1	118.8
	MAP	11.8	23.6	35.4	47.3	59.1
	K_2SO_4	29.6	59.3	88.9	118.6	148.3
	$MgSO_4$	29.6	59.2	88.8	118.4	148
	Micronutrients	3.5	7.0	10.5	14	17.5
	CE (dS m^{-1})	**1.0**	**1.6**	**2.2**	**2.8**	**3.4**
Solution B	$Ca(NO_3)_2$	56.2	112.4	168.6	224.8	281
	CE (dS m^{-1})	**1.0**	**1.5**	**2.0**	**2.6**	**3.2**

Maximum 3 L each treatment per day per plant. After each nutrient solution were applied 1.5 to 3L water in each plant per day; 3 times per day)

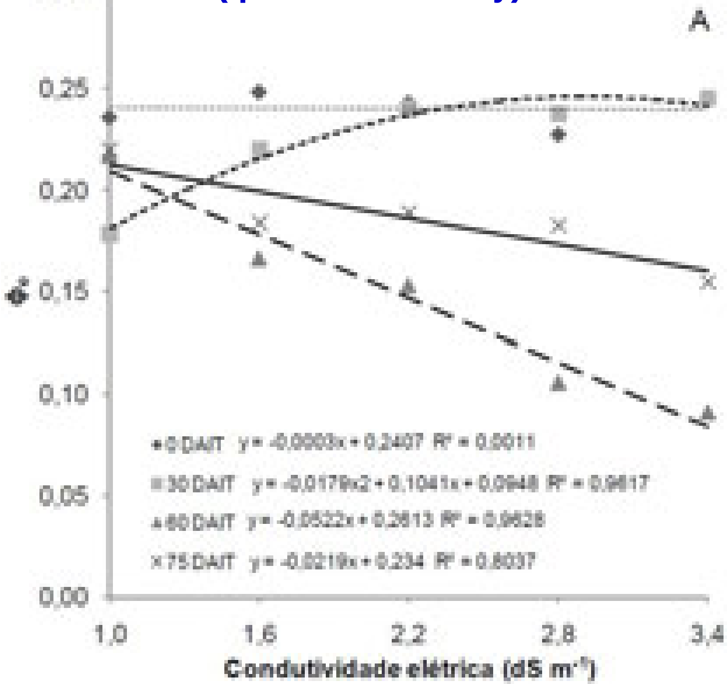

A
A (µmol CO2 m-2 s-1)
0 DAIT y = -0,4262x + 13,797 R² = 0,2241
30 DAIT y = -5,2669x + 25,305 R² = 0,9665
60 DAIT y = 1,1536x + 19,261 R² = 0,5267
75 DAIT y = -4,608x + 23,814 R² = 0,8966
Condutividade elétrica (dS m-1)
B
gs (mol m-2 s-1)
0 DAIT y = -0,0024x + 0,5291 R² = 0,0008
30 DAIT y = -0,0893x + 0,4425 R² = 0,9022
60 DAIT y = -0,2041x + 0,9087 R² = 0,8313
75 DAIT y = 0,0607x + 0,5316 R² = 0,8856
Condutividade elétrica (dS m-1)


C
E (mmol m-2 s-1)
16
14
12
10
8
6
4
2
0
0 DAIT y = 0,0375x + 8,855 R² = 0,003
30 DAIT y = 0,4188x + 12,026 R² = 0,5953
60 DAIT y = -1,85x + 11,108 R² = 0,9702
75 DAIT y = -1,7569x + 11,874 R² = 0,8676
1,0
1,6
2,2
2,8
3,4


15 DAIT
A
A (μmol m-2 s-1)
FFF (μmol m-2 s-1)
1 dS/m
1,6 dS/m
2,2 dS/m
2,8 dS/m
3,4 dS/m
75 DAIT
B
A (μmol m-2 s-1)
FFF (μmol m-2 s-1)
1 dS/m
1,6 dS/m
2,2 dS/m
2,8 dS/m
3,4 dS/m



Φe = is the initial slope of the light response curve ETR versus PAR(quantum efficiency)

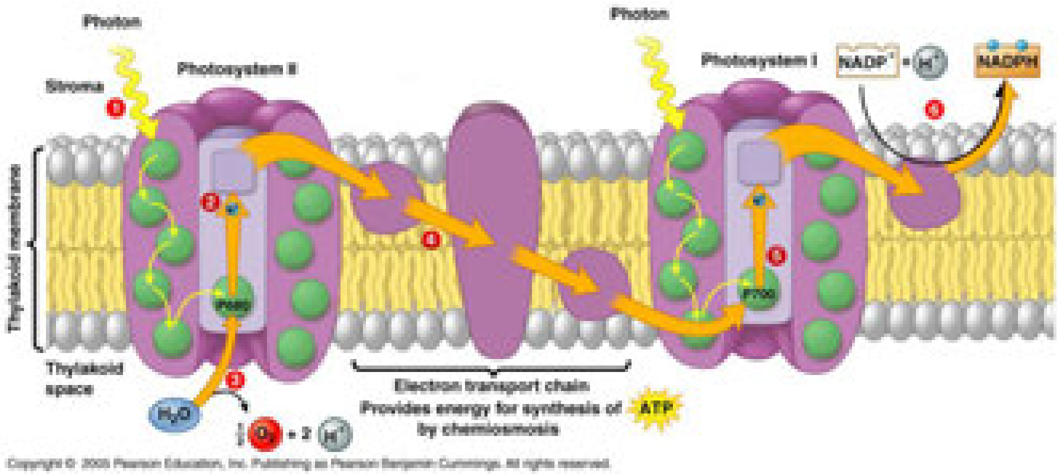


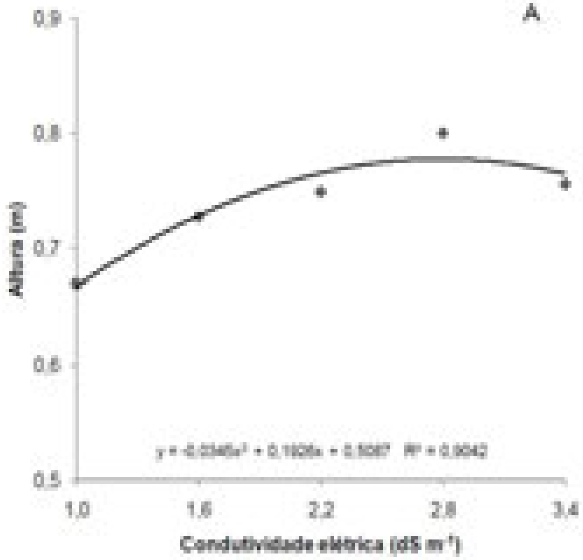
PI=(RC/ABS) x (TR/DI) x (ET/(TR-ET))

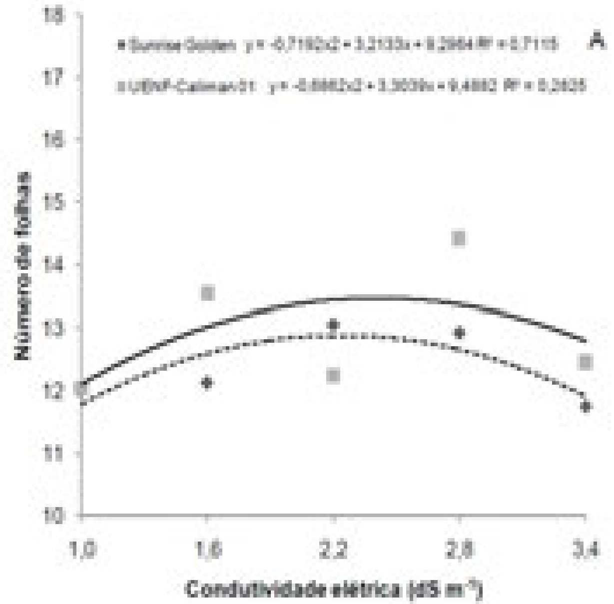
(RC/ABS): Active RC density on a Chl basis

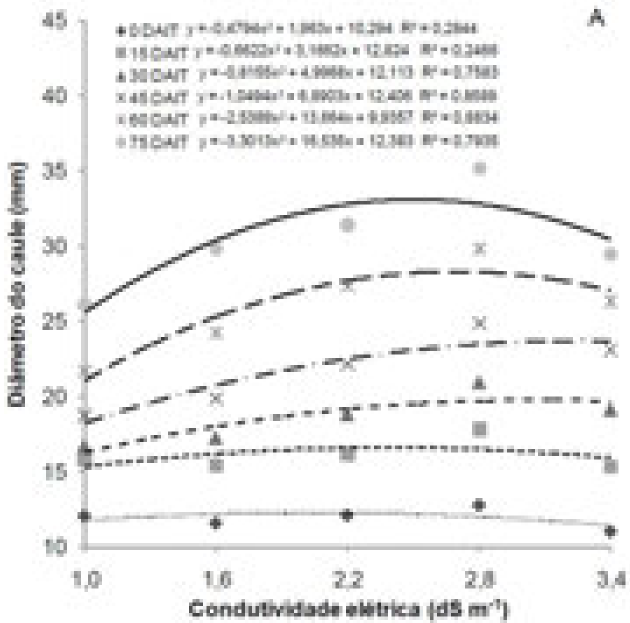
(F_V/F_0): Performance due to trapping probability $\boldsymbol{F_V/F_0=TR/DI}$

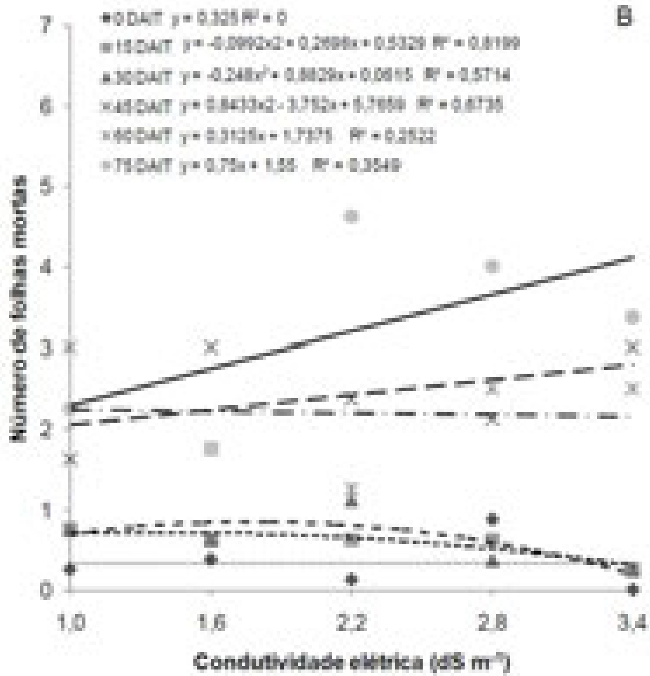
(ET/(TR-ET): Performance due to electron-transport probability




A
Altura (m)
0,9
0,8
0,7
0,6
0,5
y = -0,0346x² + 0,1926x + 0,5087 R² = 0,9042
1,0
1,6
2,2
2,8
3,4
Condutividade elétrica (dS m⁻¹)


Sunrise Golden y = -0,7192x2 + 3,2133x + 9,2964 R² = 0,7115
UENF-Caliman 01 y = -0,6862x2 + 3,3039x + 9,4882 R² = 0,2625
A
Número de folhas
18
17
16
15
14
13
12
11
10
1,0
1,6
2,2
2,8
3,4
Condutividade elétrica (dS m⁻¹)

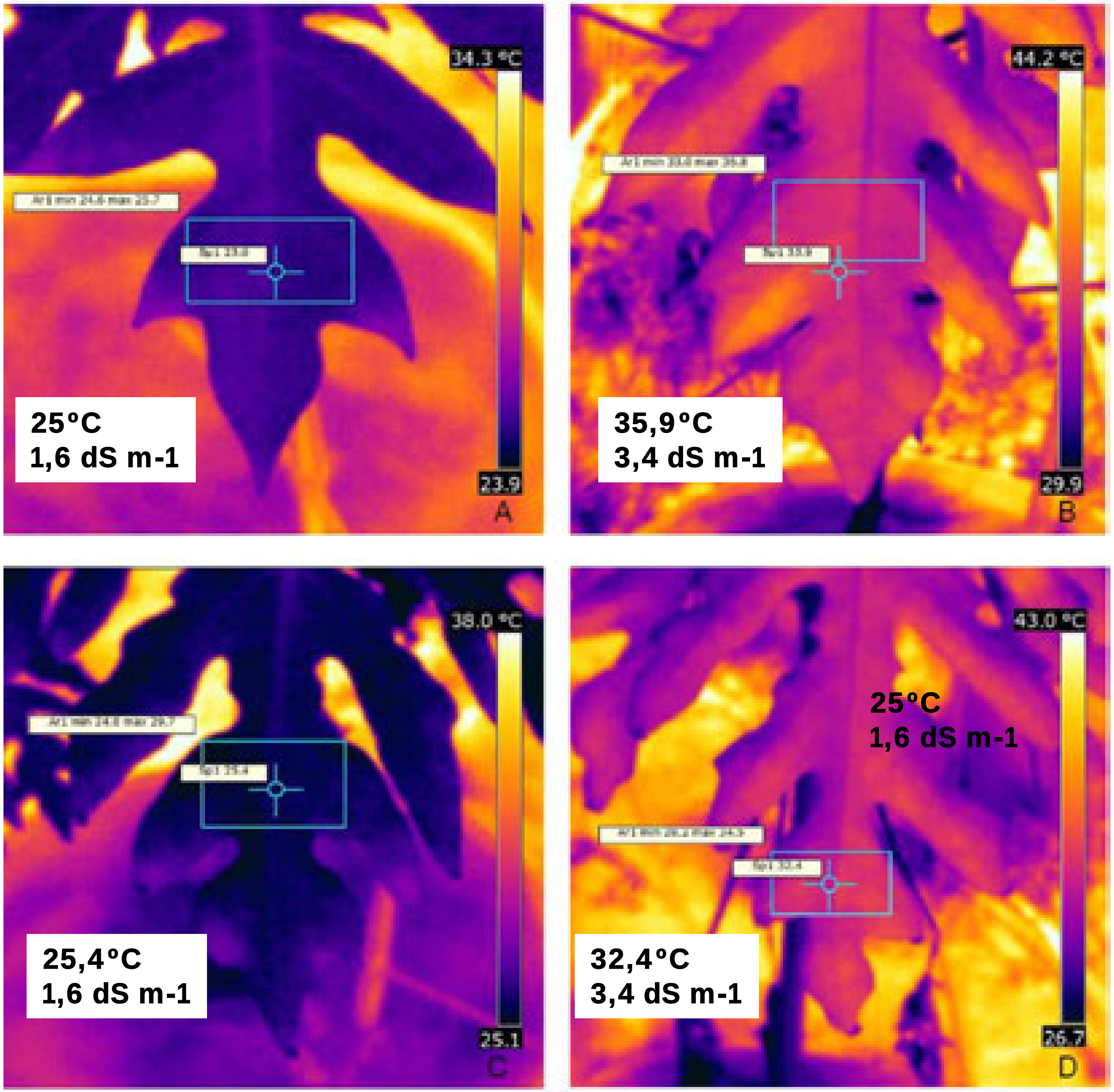

0 DAIT y = -0,4794x² + 1,963x + 10,294 R² = 0,2844
15 DAIT y = -0,6622x² + 3,1662x + 12,624 R² = 0,2466
30 DAIT y = -0,8105x² + 4,9968x + 12,113 R² = 0,7583
45 DAIT y = -1,0484x² + 6,8903x + 12,406 R² = 0,8689
60 DAIT y = -2,5389x² + 13,664x + 9,9557 R² = 0,8834
75 DAIT y = -3,3013x² + 16,538x + 12,363 R² = 0,7936
A
Diâmetro do caule (mm)
45
40
35
30
25
20
15
10
1,0
1,6
2,2
2,8
3,4
Condutividade elétrica (dS m⁻¹)


0 DAIT y = 0,325 R² = 0
15 DAIT y = -0,0992x2 + 0,2698x + 0,5329 R² = 0,8199
30 DAIT y = -0,248x² + 0,8829x + 0,0615 R² = 0,5714
45 DAIT y = 0,8433x2 - 3,752x + 5,7659 R² = 0,6735
60 DAIT y = 0,3125x + 1,7375 R² = 0,2522
75 DAIT y = 0,75x + 1,55 R² = 0,3549
B
Número de folhas mortas
7
6
5
4
3
2
1
0
1,0
1,6
2,2
2,8
3,4
Condutividade elétrica (dS m⁻¹)

75 DAP

Golden

UENF/ Caliman



Relationships between sap-flow measurements, whole-canopy transpiration, and reference evapotranspiration in field-grown papaya (*carica papaya* l.)

Summer: (clear sky, during 4 days)

PPF_{max}: 2400 μmol m^{-2} s^{-1}

T_{max}: 38ºC

VPD_{max}: 4 kPa

Winter: (clear sky during 4 days)

PPF_{max}: 1400 μmol m^{-2} s^{-1}

T_{max}: 33ºC

VPD_{max}: 3.5 kPa

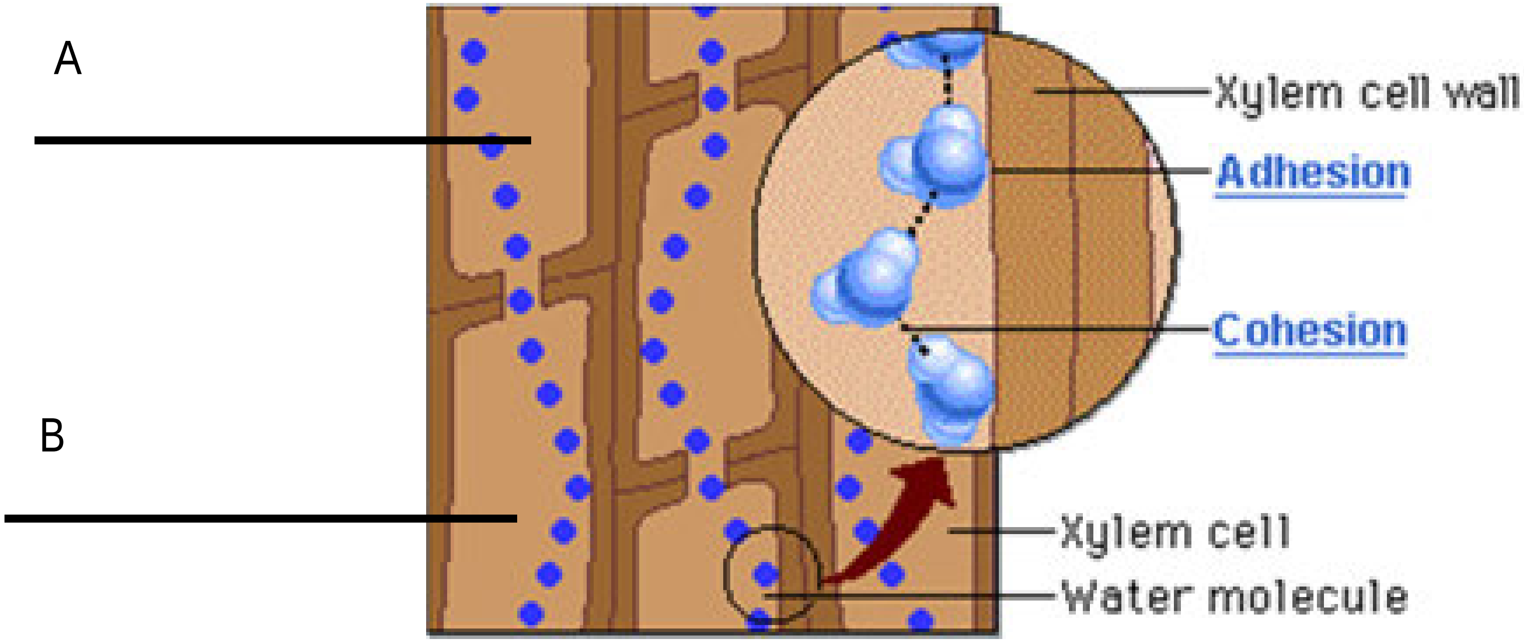
The crop was irrigated with a drip/fertigation system providing supplemental irrigation of **10** (winter) and **16 L per plant per day** (summer)

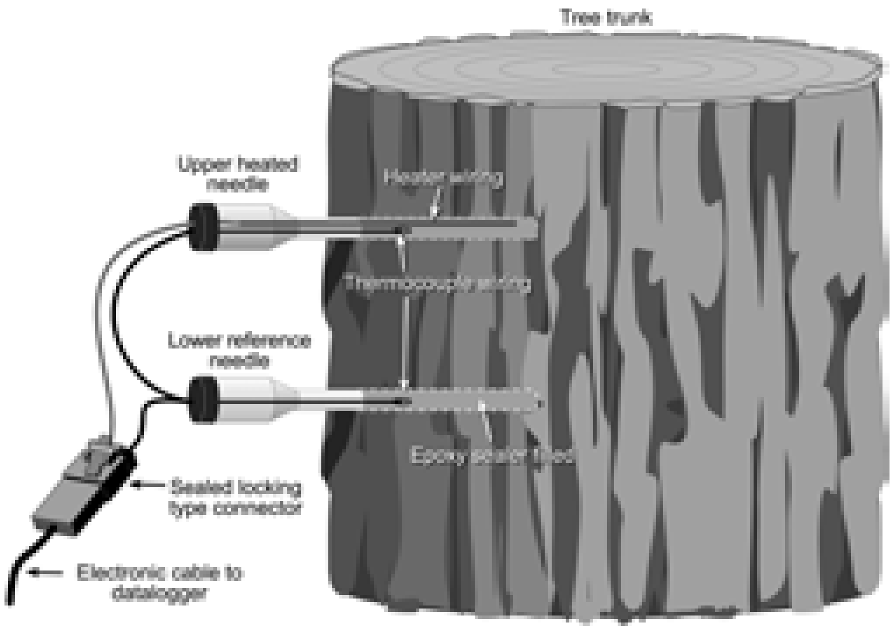
Under the environmental conditions evaluated :
(4 sunny days)

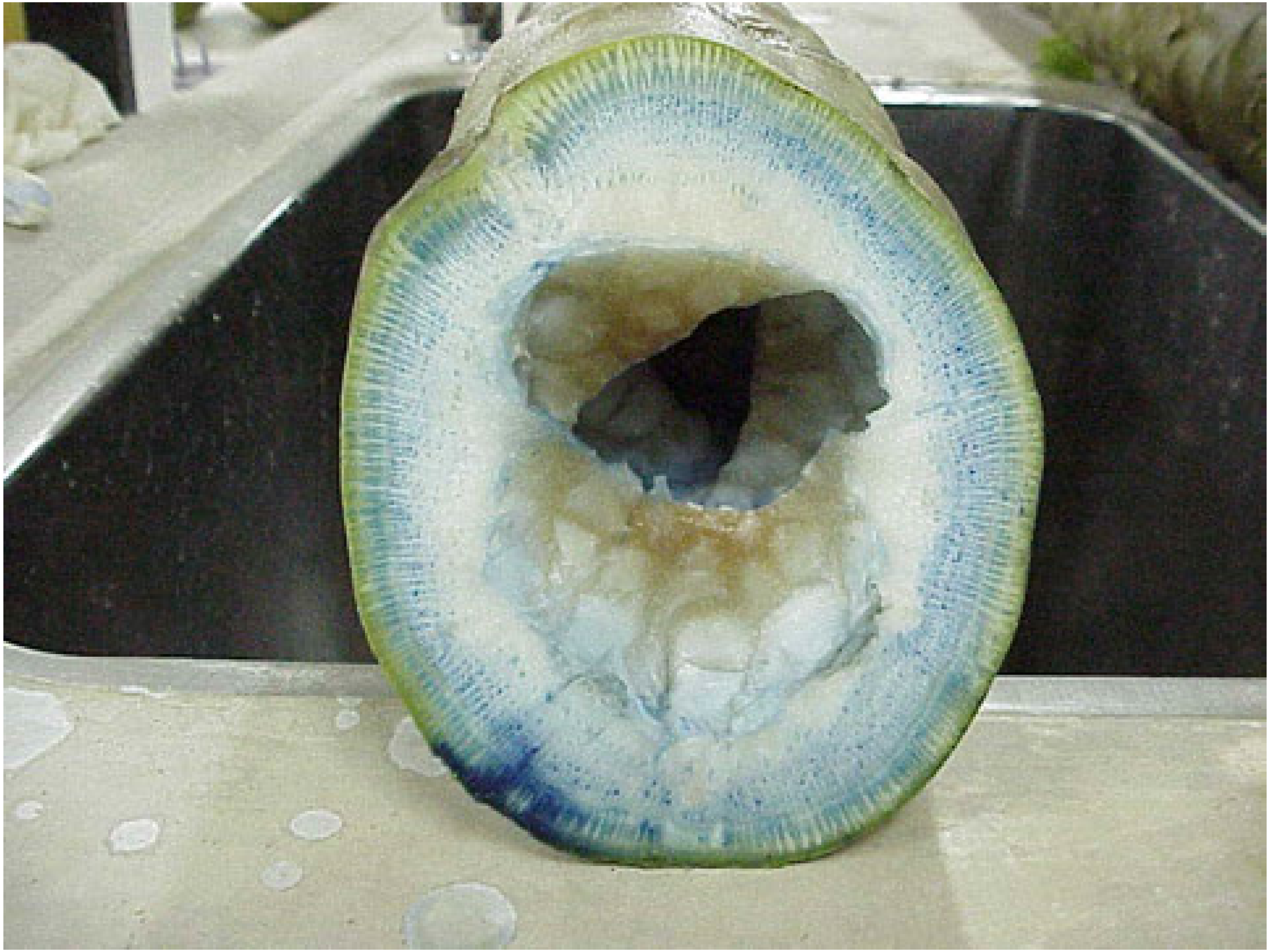
Winter:
Maximum vapor pressure deficit (VPD_{air})=3.5 kPa
Air maximum temperature of 33°C
Maximum PPF: 2400 μmol m^{-2} s^{-1}

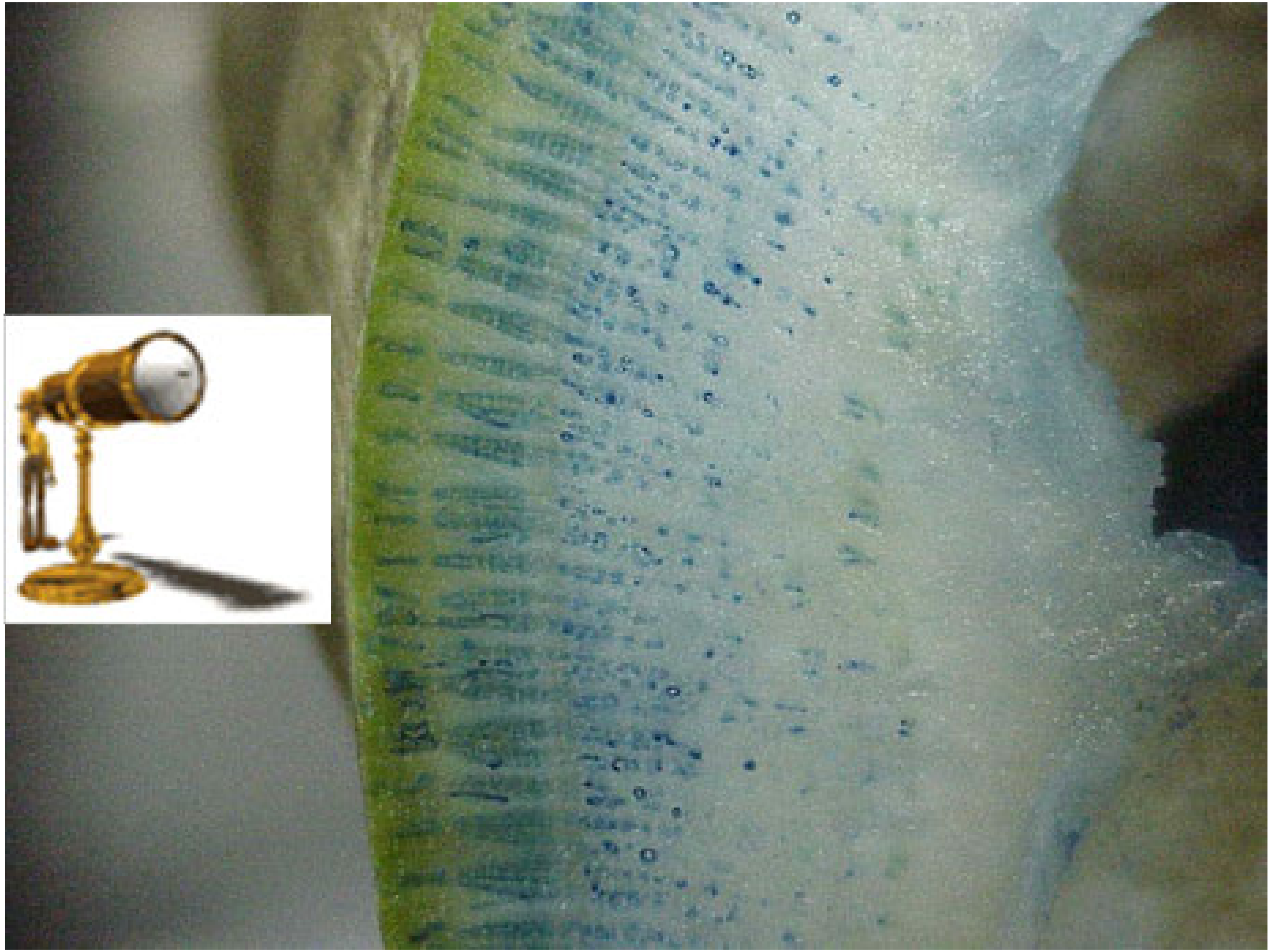
Summer
Maximum VPD_{air}=4.0 kPa
Air maximum temperature of 38°C
Maximum PPF : 1400 μmol m^{-2} s^{-1}

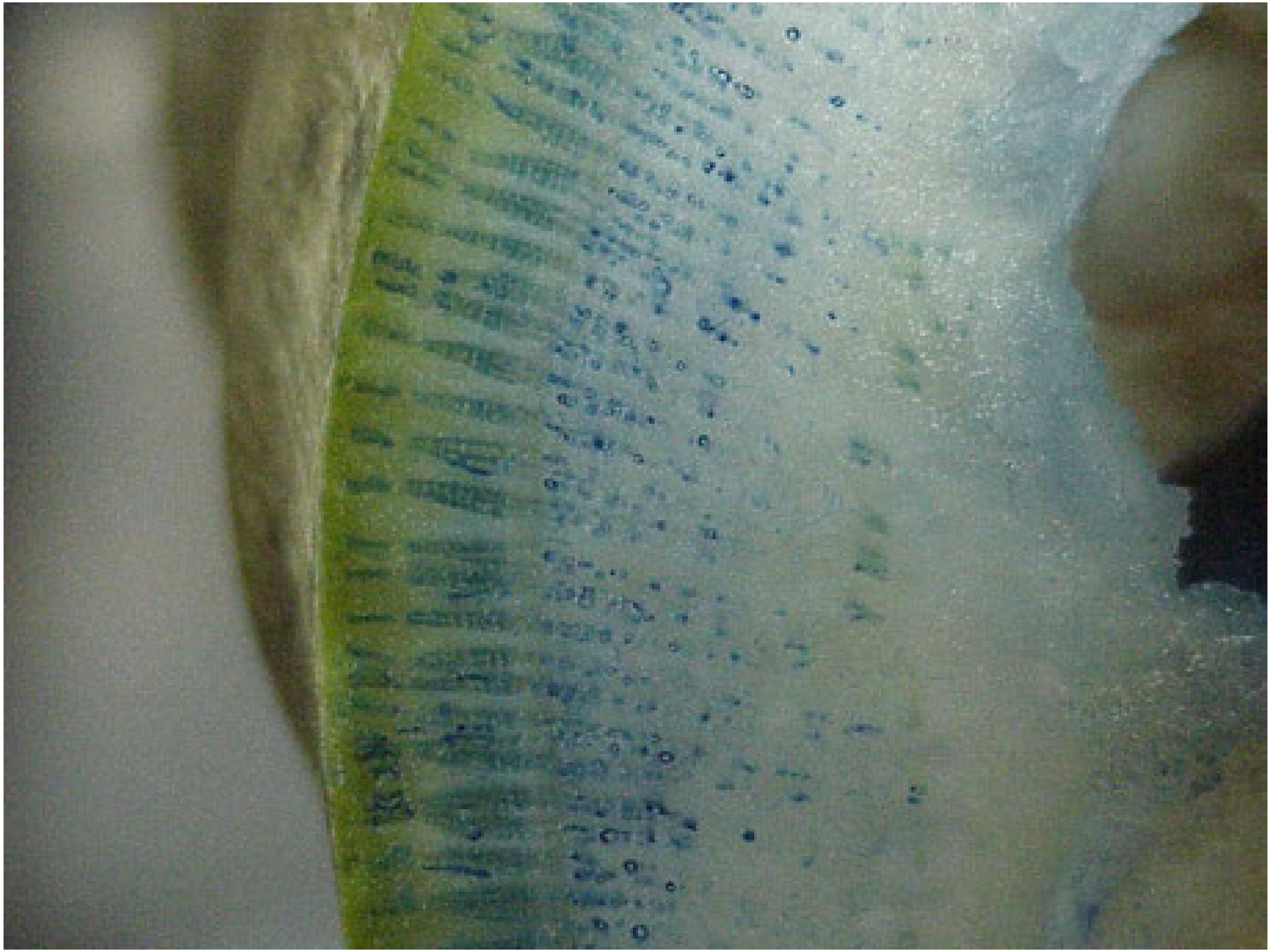
Leaf area each plant
5 months old
Winter :3.5m^2
Summer: 4 m^2

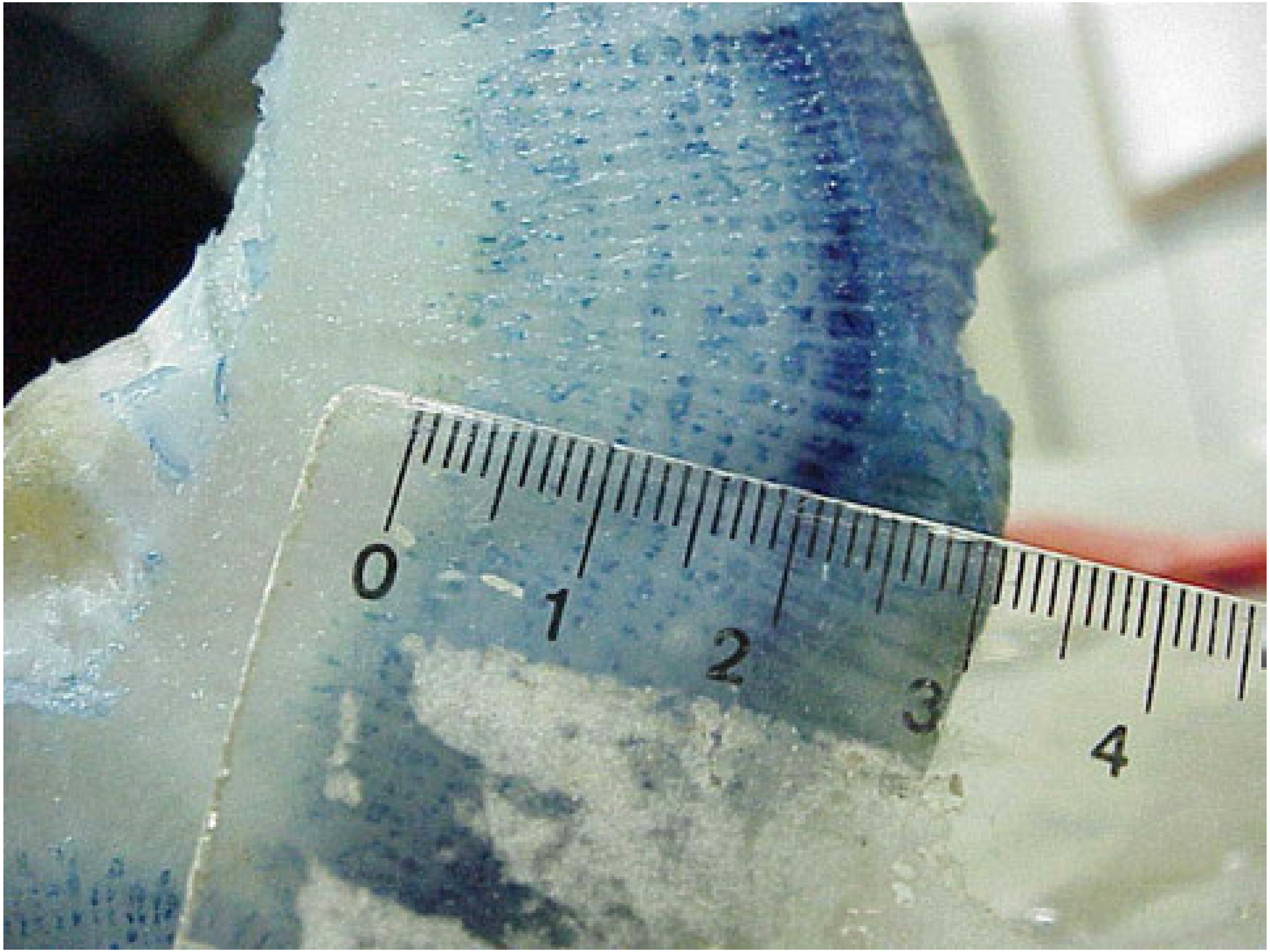

A
B
Xylem cell wall
Adhesion
Cohesion
Xylem cell
Water molecule


Tree trunk
Upper heated needle
Heater wiring
Thermocouple wiring
Lower reference needle
Sealed locking type connector
Electronic cable to datalogger








0
1
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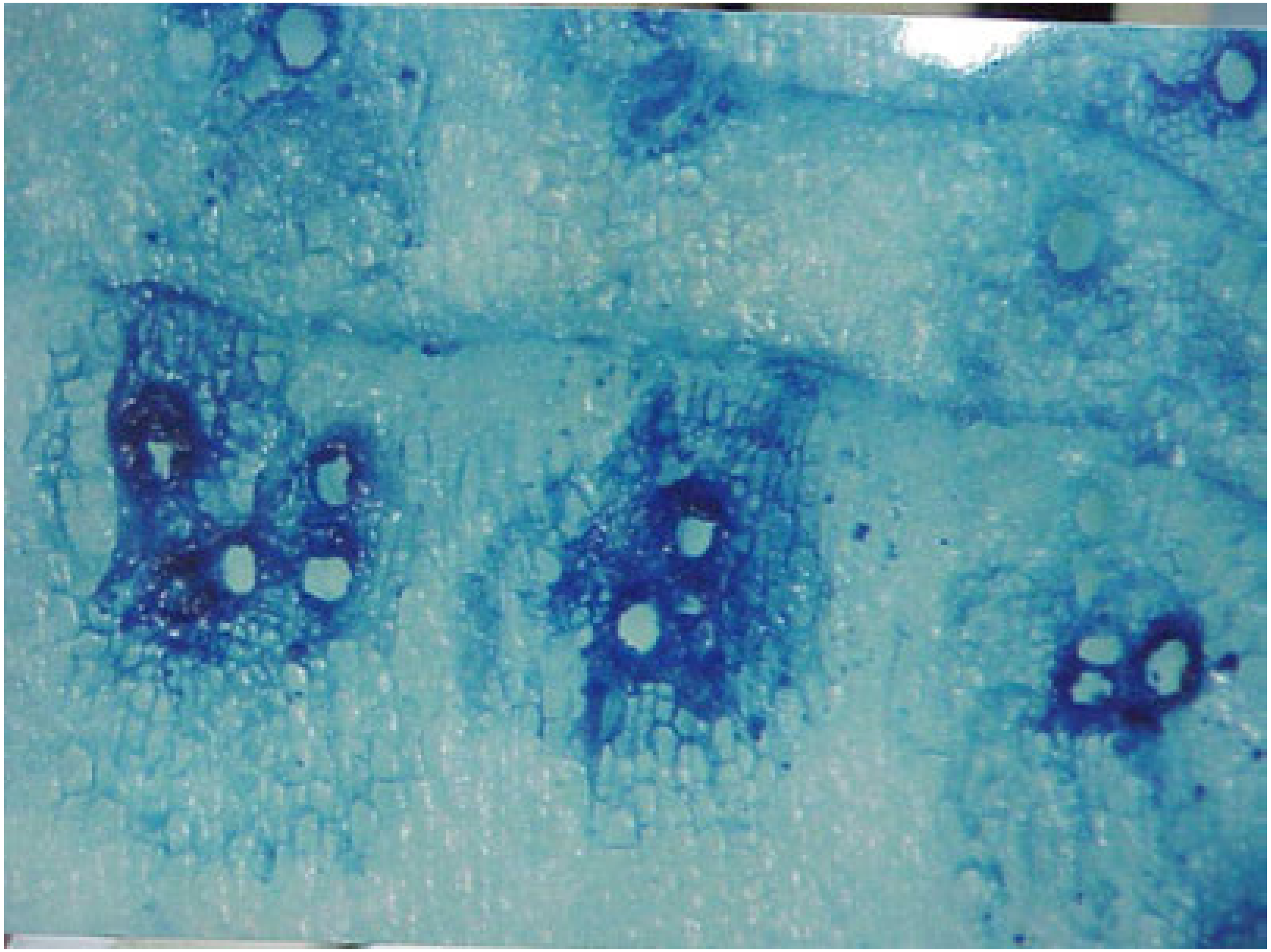
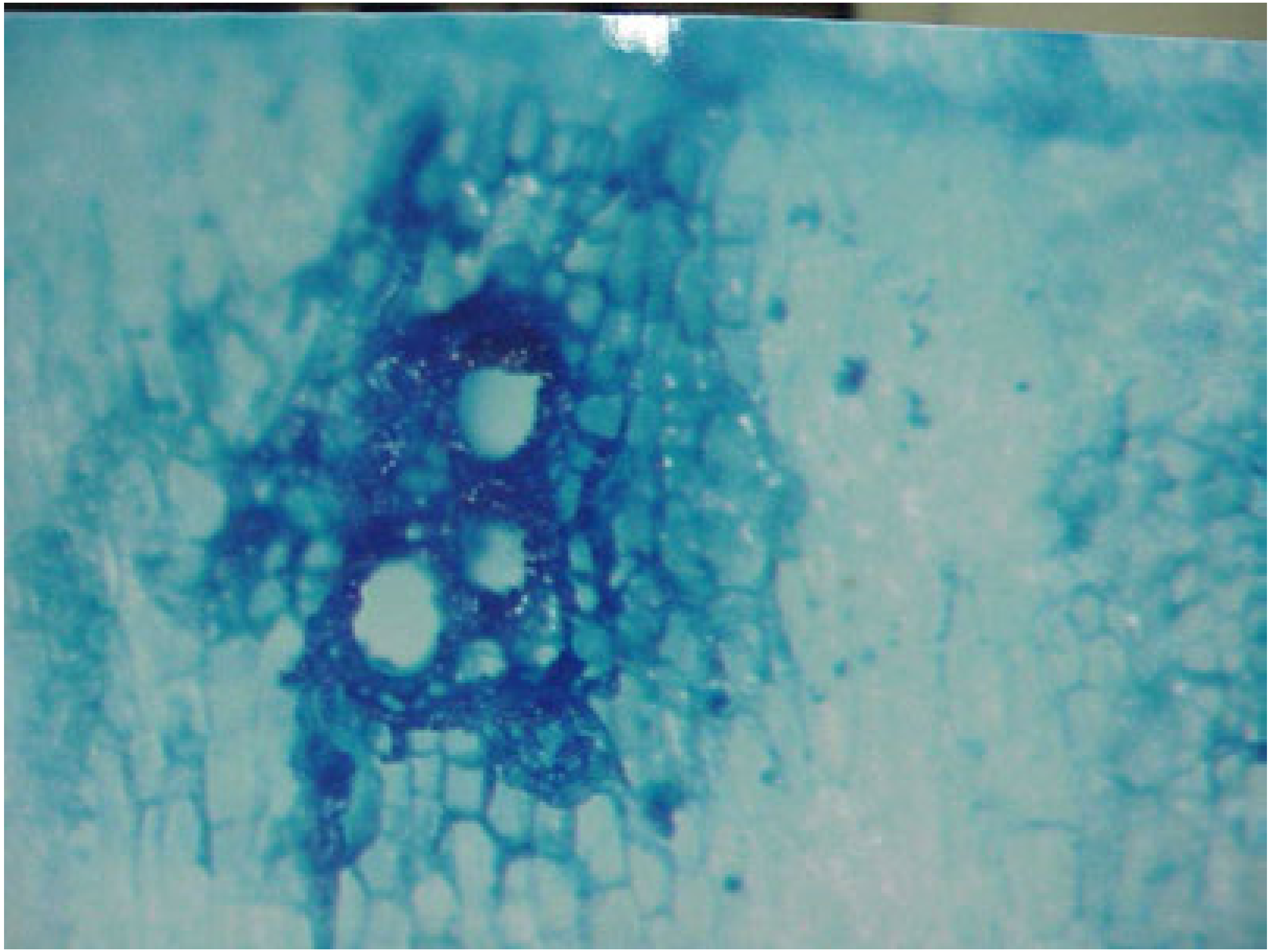
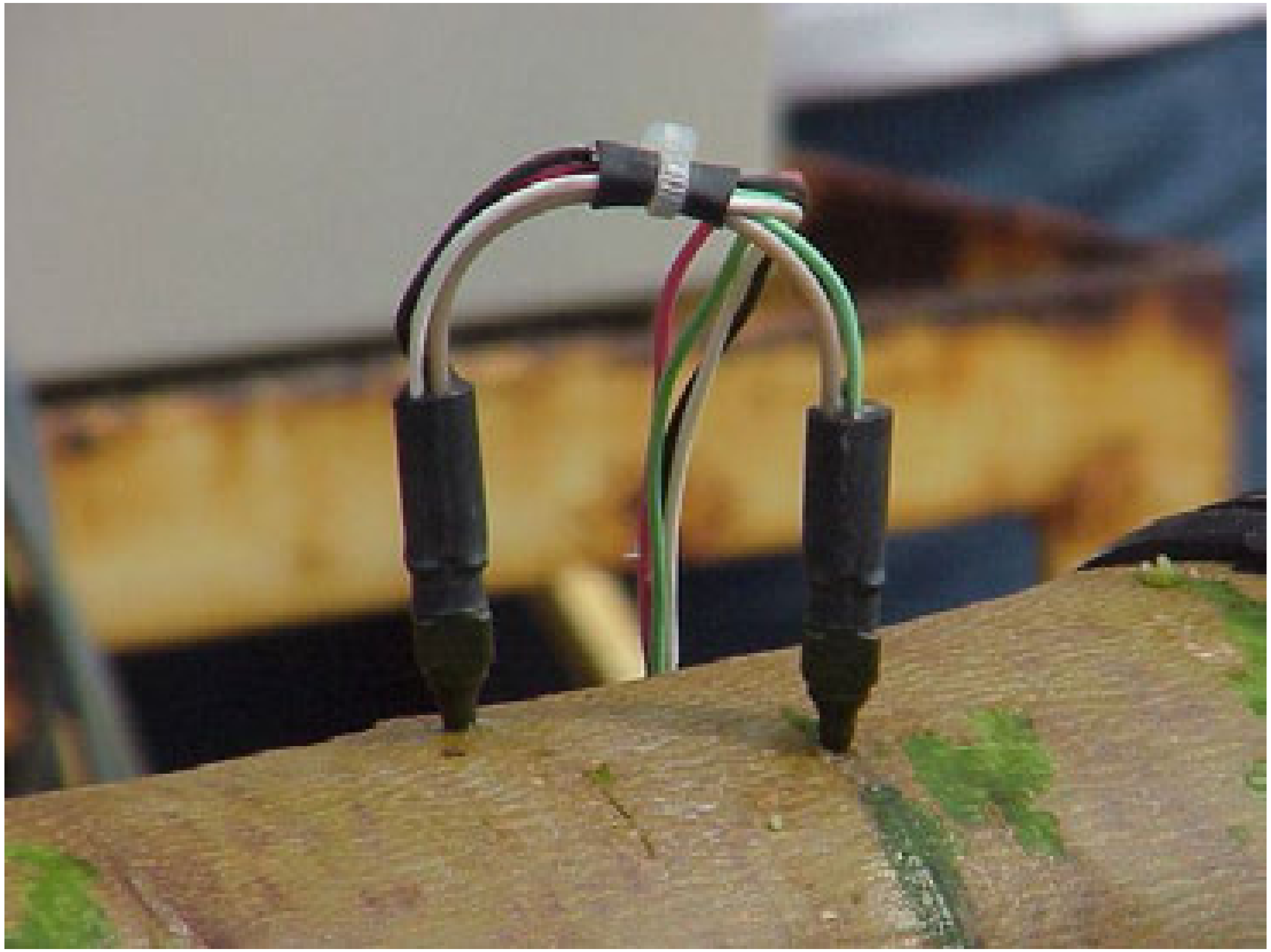
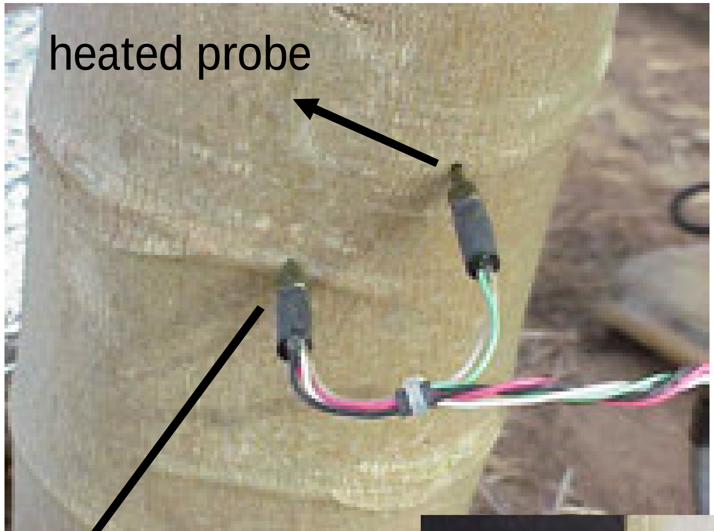
4



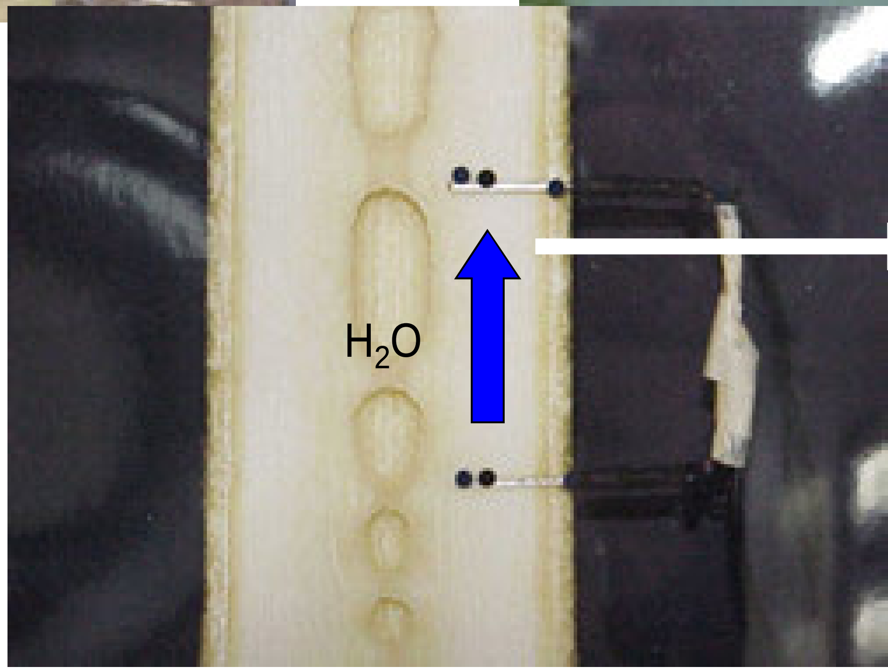




Effects on sap flow

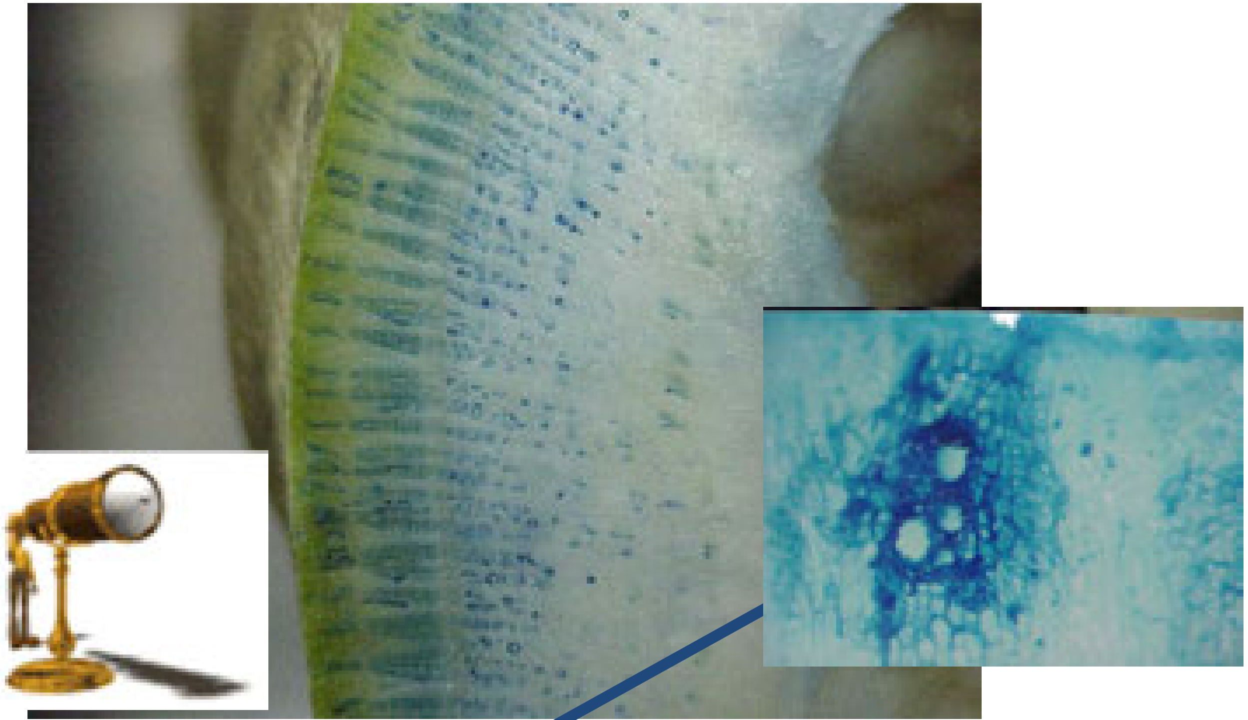


non-heated probe



Sap flow measure differences between heated and non-heated probe

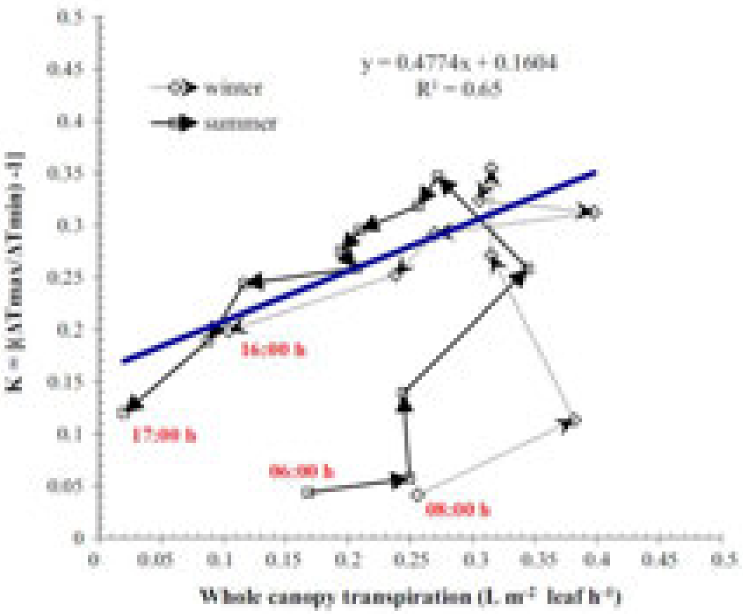
Water reduce temperature



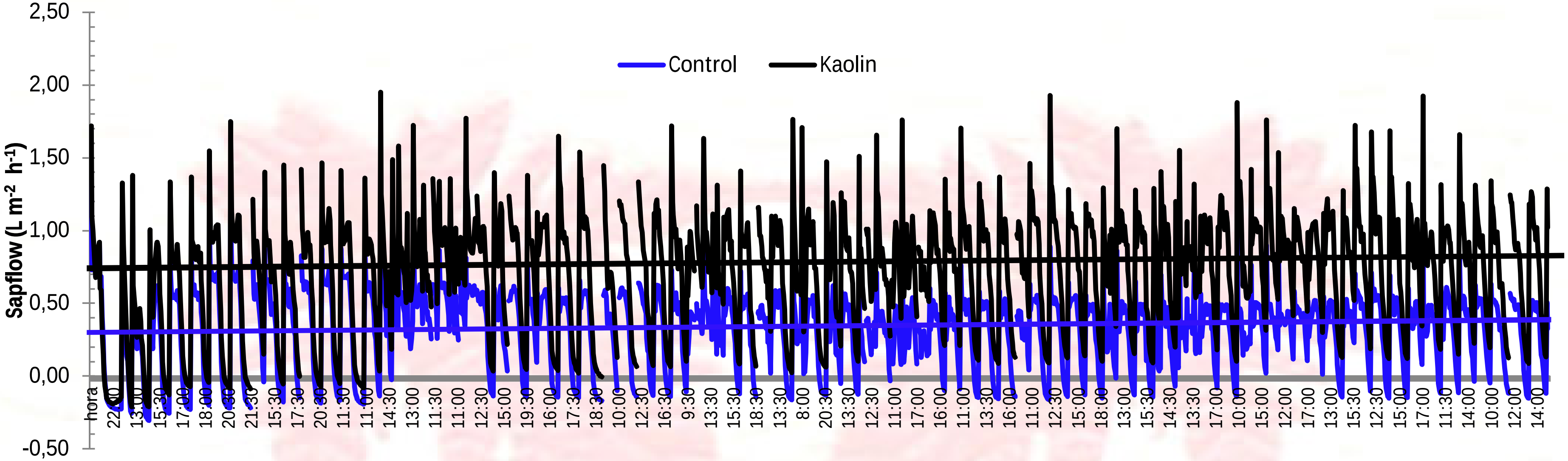
Xylem vessel

[reviewer1]Is night time relevant?

Fig. 5 Relationship between mean hourly whole-canopy transpiration and the xylem sap flow heat coefficient (K) in 'Gran Golden' papaya during four days in winter and summer. Arrows indicate the chronological progression during the day. Whole canopy transpiration data excluded from the regression were 8:00 to 9:00 h in winter related to dew on the leaf surfaces and Mylar chamber and lag phase in summer from 6:00 to 8:00 h



K is the heat coefficient:
ΔT_m : the maximum temperature difference (°C) between sensors in active xylem (night time), and ΔT is the temperature difference (°C) between sensors in active xylem



May to July (winter dry season)(104days)

Plant leaf area: **$5m^2$**

Kaolin particles:
0.70 L h m^{-2} x $5m^2$ = 3.5 L h^{-1} $plant^{-1}$ x 8h = **28 L H_2O $plant^{-1}$ day^{-1}**

Control:
0.32 L h m^{-2} = 1.60 L h plant x 8h = **12.8 L H_2O $plant^{-1}$ day^{-1}**

Maximum light = 2300µmol m^{-2} s^{-1} = 1000 W m^{-2}

Mycorrhizal fungi effects on papaya productivity

The beneficial effects of arbuscular mycorrhizal (AM) fungi in the plant kingdom and agricultural cropping systems are well documented, and include increased P, water, and nutrient uptake as well as improved pest resistance (Harley and Smith, 1983; Bethlenfalvay and Linderman, 1992)

Arbuscular mycorrhizal fungi colonize papaya under natural conditions. Papaya appears to be very dependent on AM since plants in sterilized soil, as compared to inoculated, showed poor growth and particularly P uptake (Habte, 2000)

Mohandas (1992) reported that AM inoculation of papaya seedlings increased growth, P concentration and acid phosphatase activity in leaves

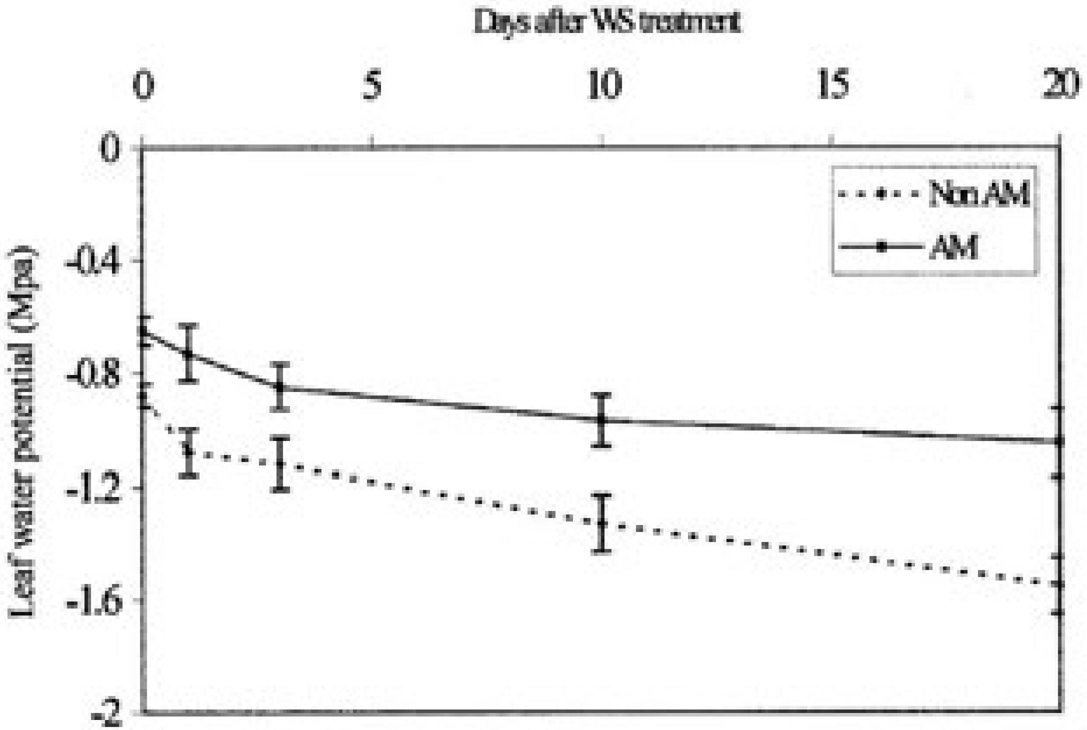


Fig. 1 Leaf water potential of papaya trees inoculated with an arbuscular mycorrhizal (*AM*) fungus, *Gigaspora margarita*, and non-inoculated (*Non AM*) trees during period of water stress (*WS*). *Vertical bars* indicate SE ($n=3$)

Table 1 Biomass yield (g) of papaya trees inoculated with an arbuscular mycorrhizal (*AM*) fungus, *Gigaspora margarita*, and non-inoculated (*Non AM*) trees under irrigated and water-stress conditions. The data are means ± standard error (SE) ($n = 3$) (*RFW* root fresh weight, *TFW* total fresh weight)

Treatment	Biomass yield			
	Irrigated		Water stressed	
	RFW	TFW	RFW	TFW
Non AM	55.2 ± 5.8	99.4 ± 9.8	44.0 ± 5.4	75.8 ± 7.3
AM	85.9 ± 6.5	141.1 ± 10.5	66.4 ± 4.9	119.6 ± 6.6

20 days of water-stress treatment

Treatments were applied 3 months after planting

Table 2 Concentrations of 1-aminocyclopropane-1-carboxylic acid (*ACC*) and ethylene in papaya roots inoculated with an arbuscular mycorrhizal (*AM*) fungus, *Gigaspora margarita*, and non-inoculated (*Non AM*) trees under irrigated and water-stress conditions. The data are means ± SE ($n = 3$)

Treatment	ACC (nmol/g fresh wt.)		Ethylene (ppm)	
	Irrigated	Water stressed	Irrigated	Water stressed
Non AM	0.14 ± 0.04	0.62 ± 0.04	0.93 ± 0.04	1.41 ± 0.04
AM	0.06 ± 0.01	0.41 ± 0.04	1.35 ± 0.04	1.23 ± 0.03

20 days of water-stress treatment

Mycorrhiza establishment may result in the control of ethylene levels as one mechanism of reducing damage by water stress in papaya plants.

Besmer and Koide (1999) showed that mycorrhizal colonization can decrease ethylene concentration in flowers, which might explain the increased vase-life of cut flowers.

AM colonization may act as an inhibitor of ethylene biosynthesis by influencing ACC conversion to ethylene

Mechanical root restriction

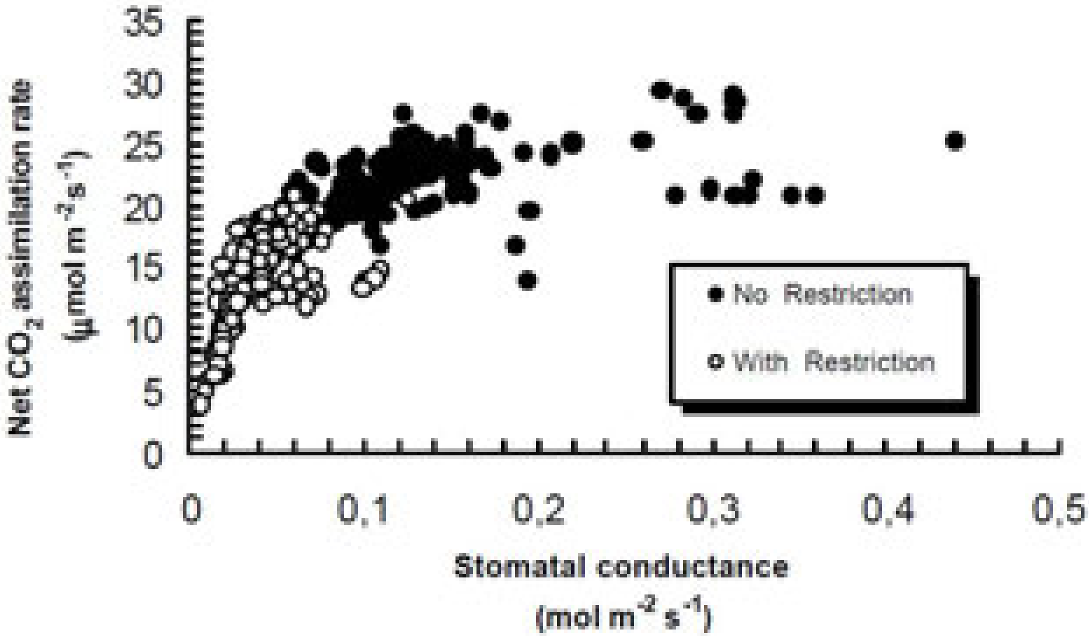


TABLE 1 - Textural class, bulk density, particle density, porosity and macroporosity of the soil in Macaé/RJ/Brazil

Horizon	B_d^z (g cm^{-3})	P_d^y (g cm^{-3})	Soil Porosity (%)	Macroporosity^x (%)
A^w (sandy-loam)	1.74	2.60	33.1	13.3
B^v (clay)	1.64	2.61	37.2	7.9

B_d^z = Bulk Density, P_d^y = Particle Density, Macroporosity^x (0.1atm), (sandy-loam, 58% coarse, 15% fine sandy, 07% silt and 20% clay)^w, (clay, 25% coarse, 19% fine sandy, 08% silt and 48% clay)^v.

TABLE 4 - Net CO_2 assimilation rate (A), stomatal conductance (g_s), intercellular partial pressure CO_2 (c_i) and leaf temperature (T_l) of four papaya (*Carica papaya* L.) genotypes as influenced by root zone restriction in Macaé/RJ/Brazil. Determined in the third day after the irrigation.

Genotypes	A^z (μmol m^{-2} s^{-1})		g_s^z (mol m^{-2} s^{-1})		c_i^z (μL L^{-1})		T_l^z (°C)	
	NR[y]	WR[x]	NR	WR	NR	WR	NR	WR
Sunrise Solo TJ	17.1 Aa[w]	10.0 Bb	0.110 Ab	0.021 Ba	282.1 Ac	261.4 Bb	36.7 Ba	38.1 Aa
Sunrise Solo 72/12	22.0 Aa	11.5 Bb	0.226 A a	0.052 Ba	296.7 Ab	271.3 Bab	35.3 Bb	36.5 Ad
Tainung 02	22.2 Aa	12.3 Bab	0.131 Ab	0.029 Ba	309.4 Aa	276.8 Ba	36.8 Ba	37.6 Ab
Know -You 01	21.8 Aa	15.2 Ba	0.210 Aa	0.062 Ba	293.2 Abc	282.8 Aa	35.7 Bab	37.8 Aab

[z] Determined 150 days after transplanting, on third day after irrigation; Quantum flux of photons 1650.60 ± 160.90 μmol m^{-2} s^{-1}. Data collected at 9:00-11:00 AM. Air Temperature 36.90 ± 0.8°C. CO_2 concentration into chamber 360.00 ± 11.70 μL L^{-1}. Partial pressure of water vapour into chamber 3.59 ± 0.11 kPa; Soil moisture on volume basis 9.36 ± 1.73 %, [Field Capacity=11.00%]; [y] NR= Area with no restriction to root growth, [x] WR= Area with restriction of root growth ; [w] Average followed by the same small letters in columns or capital letters in the rows (for each characteristic) did not differ at the probability level of 5% ($p<0.05$) using Duncan's Multiple Range Test.

Tables

1. Total leaf number (TLN), average leaf area (ALA), length of leaf central vein (LLCV), total leaf area (TLA) of four papaya (*Carica papaya* L.) genotypes as influenced by root zone restriction in Macaé/RJ/Brazil.

	TLN[z]		ALA[x] (m^2)		LLCV[y] (m)		TLA[x] (m^2)	
Genotypes	NR[v]	WR[w]	NR	WR	NR	WR	NR	WR
Sunrise Solo TJ	24.8 Aa	14.3Ba[u]	0.18Ab	0.15Bb	0.40Ab	0.35Bc	4.55Ab	2.09Bb
Sunrise Solo 72/12	22.0 Aa	17.0Ba	0.20Ab	0.17Bb	0.41Ab	0.38Bb	4.46Ab	2.88Ba
Tainung 02	25.5 Aa	10.7Bb	0.21Ab	0.15Bb	0.42Ab	0.34Bc	5.25Ab	1.61Bb
Know -You	24.3 Aa	16.8Ba	0.27Aa	0.22Ba	0.49Aa	0.44 Ba	6.52Aa	3.73Ba

[z] Determined at fifteen months after transplant.

[y] Determined by millimeter ruler.

[x] Determined by equation, fifteen months after transplant: Log LA= 0.315 + 1.85 Log LLCV, R^2=0.898 were LA = Leaf Area and LLCV = length of leaf central vein.

[w] WR= Area with restriction on root growth system. Average effective deepness with 0.35 ± 0.05 m, with 4.12 ± 0.2 MPa of the maximum force.

[v] NR= Area with no restriction to root growth. Minimum effective deepness with 0.60 m, that received a force lower than 2.30 MPa for penetration. Effective deepness was determined using penetrographer (SOILCONTROL, Santo Amaro, SP, Brazil).

[u] In the horizontal, average followed by the same capital letters for each analyzed characteristic are not significantly different at the 5% probability level using the Duncan test. In the vertical, average followed by the same small letters for each analyzed characteristic are not significantly different at the 5% probability level using the Duncan test.

Tables

1. Total leaf number (TLN), average leaf area (ALA), length of leaf central vein (LLCV), total leaf area (TLA) of four papaya (*Carica papaya* L.) genotypes as influenced by root zone restriction in Macaé/RJ/Brazil.

	TLN[z]		ALA[x] (m^2)		LLCV[y] (m)		TLA[x] (m^2)	
Genotypes	NR[v]	WR[w]	NR	WR	NR	WR	NR	WR
Sunrise Solo TJ	24.8 Aa	14.3Ba[u]	0.18Ab	0.15Bb	0.40Ab	0.35Bc	4.55Ab	2.09Bb
Sunrise Solo 72/12	22.0 Aa	17.0Ba	0.20Ab	0.17Bb	0.41Ab	0.38Bb	4.46Ab	2.88Ba
Tainung 02	25.5 Aa	10.7Bb	0.21Ab	0.15Bb	0.42Ab	0.34Bc	5.25Ab	1.61Bb
Know -You	24.3 Aa	16.8Ba	0.27Aa	0.22Ba	0.49Aa	0.44 Ba	6.52Aa	3.73Ba

[z] Determined at fifteen months after transplant.

[y] Determined by millimeter ruler.

[x] Determined by equation, fifteen months after transplant: Log LA= 0.315 + 1.85 Log LLCV, R^2=0.898 were LA = Leaf Area and LLCV = length of leaf central vein.

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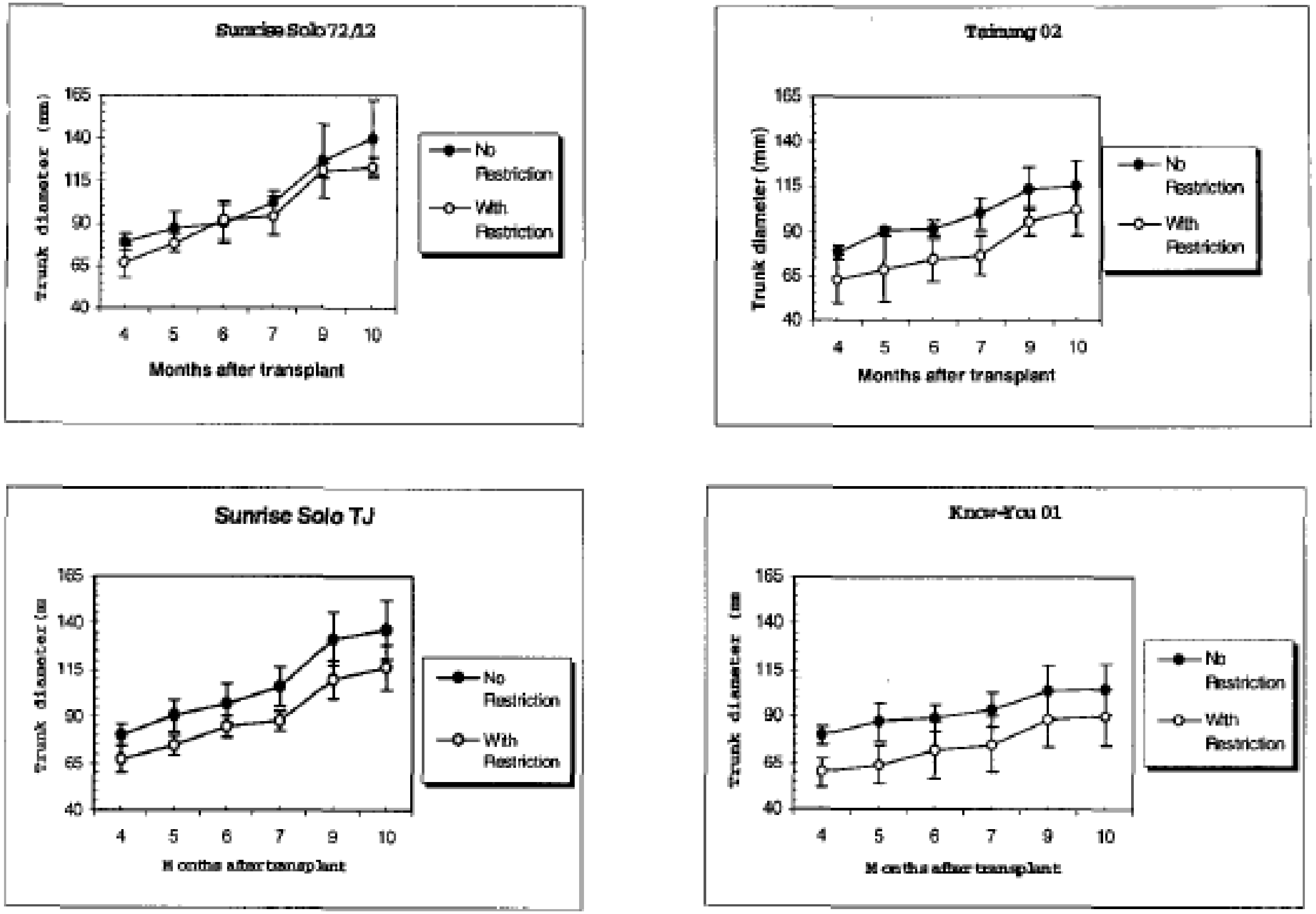
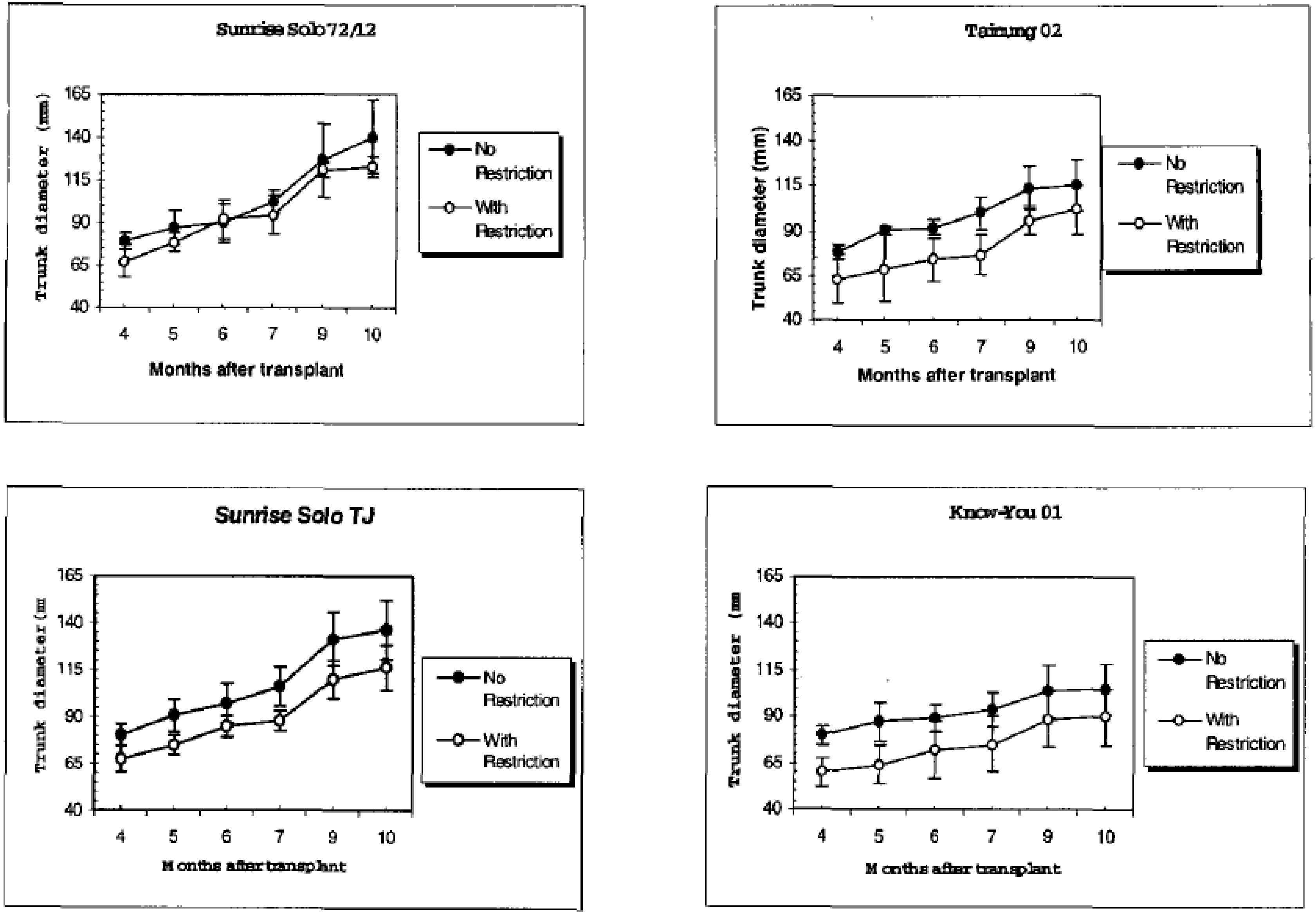


2. Seasonal changes in trunk diameter of four papaya genotypes as affected by root zone restriction in Macaé/RJ/Brazil. Vertical bars indicate standard error (n=4).



2. Seasonal changes in trunk diameter of four papaya genotypes as affected by root zone restriction in Macaé/RJ/Brazil. Vertical bars indicate standard error (n=4).

Wind

Table 1. Single leaf area, leaf expansion rate, and root extension rate of 'Tainung 2' and 'Sunrise' papaya plants exposed to or fully protected from ambient winds at the end of 3-week experiments conducted 3 to 24 May 2009 (mean wind speed = 2.37 $m \cdot s^{-1}$), 4 to 25 Sept. 2009 (mean wind speed = 3.06 $m \cdot s^{-1}$), and 6 to 27 Jan. 2010 (mean wind speed = 3.77 $m \cdot s^{-1}$).[z]

Response variable	Wind treatment: Protected	Exposed	P
	Expt. 1		
Leaf area (cm^2)	199	196	0.6087
Leaf expansion ($mm \cdot d^{-1}$)	6.83	5.85	0.0665
Root extension ($mm \cdot d^{-1}$)	6.39	6.48	0.9252
	Expt. 2		
Leaf area (cm^2)	303	149	0.0001
Leaf expansion ($mm \cdot d^{-1}$)	6.57	4.67	0.0003
Root extension ($mm \cdot d^{-1}$)	6.58	6.88	0.9692
	Expt. 3		
Leaf area (cm^2)	320	123	0.0001
Leaf expansion ($mm \cdot d^{-1}$)	7.35	2.71	0.0001
Root extension ($mm \cdot d^{-1}$)	7.38	7.44	0.8359

[z]n = 12 (mean of six 'Tainung 2' and six 'Sunrise' plants).

During Expt. 1, plants experienced mean daytime wind speeds of 3.11 $m \cdot s^{-1}$ and night wind speeds of 1.62 $m \cdot s^{-1}$. Stem height, area

During Expt. 2, ambient winds were 3.96 $m \cdot s^{-1}$ during the daytime and 2.15 $m \cdot s^{-1}$ during night hours. Significance of sources of

During Expt. 3, ambient winds were 4.25 $m \cdot s^{-1}$ during the day and 3.28 $m \cdot s^{-1}$ during the night. The repeated-measures ANOVA re-

Wind

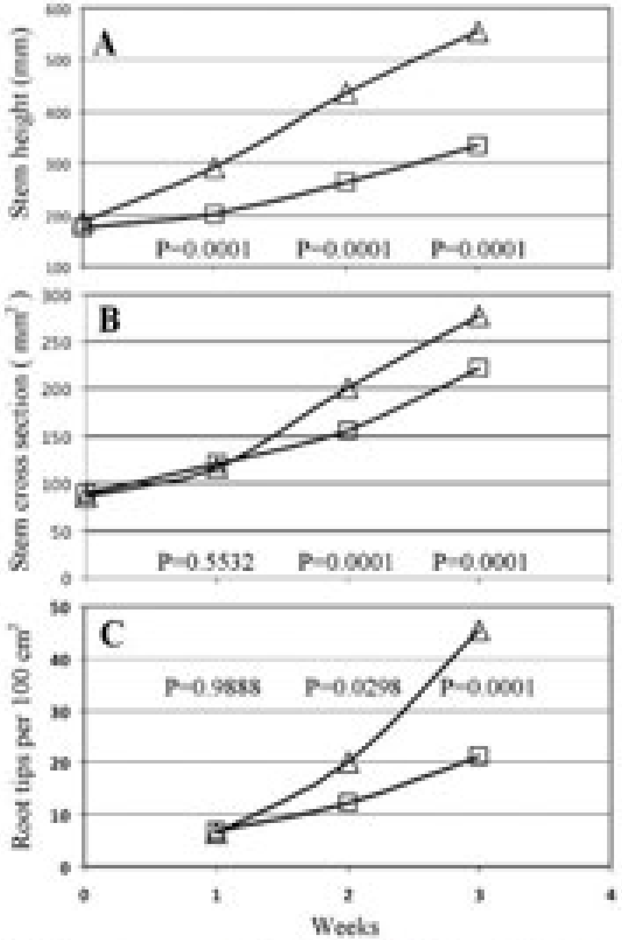


Fig. 2. Stem height (A), stem cross-section (B), and root tip density (C) of *Carica papaya* seedlings protected from (Δ) or exposed to (□) easterly ambient winds in north Guam from 4 to 25 Sept. 2009. n = 12 (mean of six 'Tainung 2' and six 'Sunrise' plants).

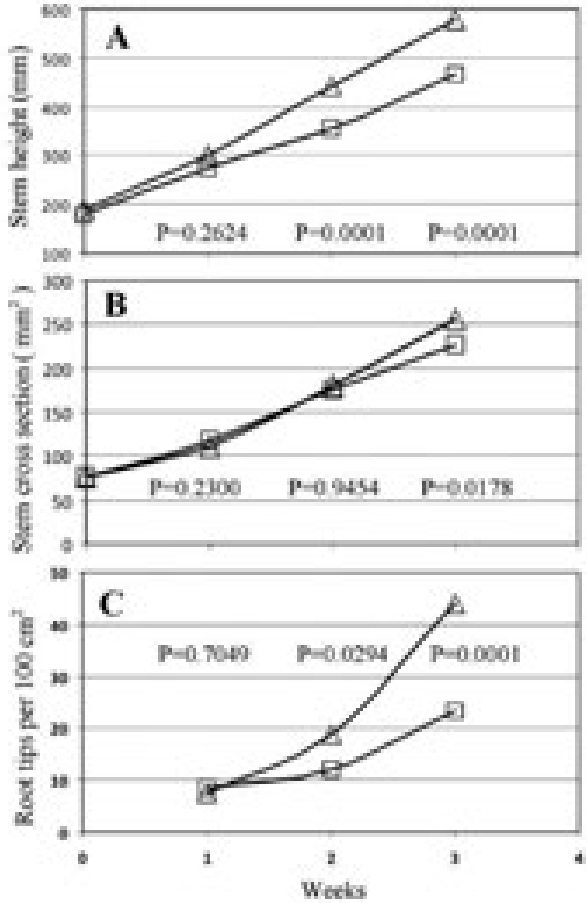


Fig. 1. Stem height (A), stem cross-section (B), and root tip density (C) of *Carica papaya* seedlings protected from (Δ) or exposed to (□) easterly ambient winds in north Guam from 3 to 24 May 2009. n = 12 (mean of six 'Tainung 2' and six 'Sunrise' plants).

Wind

Structures were constructed in a north–south direction to provide plants on the west side with one of three levels of wind exposure: 0 % (fully protected), 36 % or 100 % (fully exposed). Full protection was provided using a polypropylene sheet to exclude all ambient wind. Exposure to 36 % ambient wind was provided by covering the structure with a fabric screen. Plants receiving 100 % exposure received no protection from the ambient wind. A randomized complete block design was used, with nine structures established within three blocks.

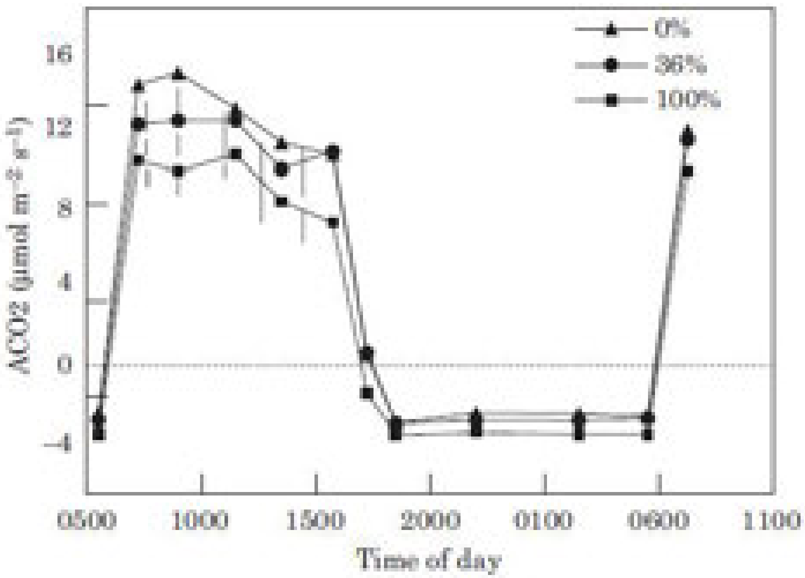


FIG. 2. Net CO_2 assimilation (A_{CO_2}) of 'Tainung 2' leaves on 14 and 15 Dec. 1995 as influenced by time of day and exposure to wind. Sunrise was at 0635 h, and sunset was at 1756 h. Vertical bars represent standard error. $n = 6$.

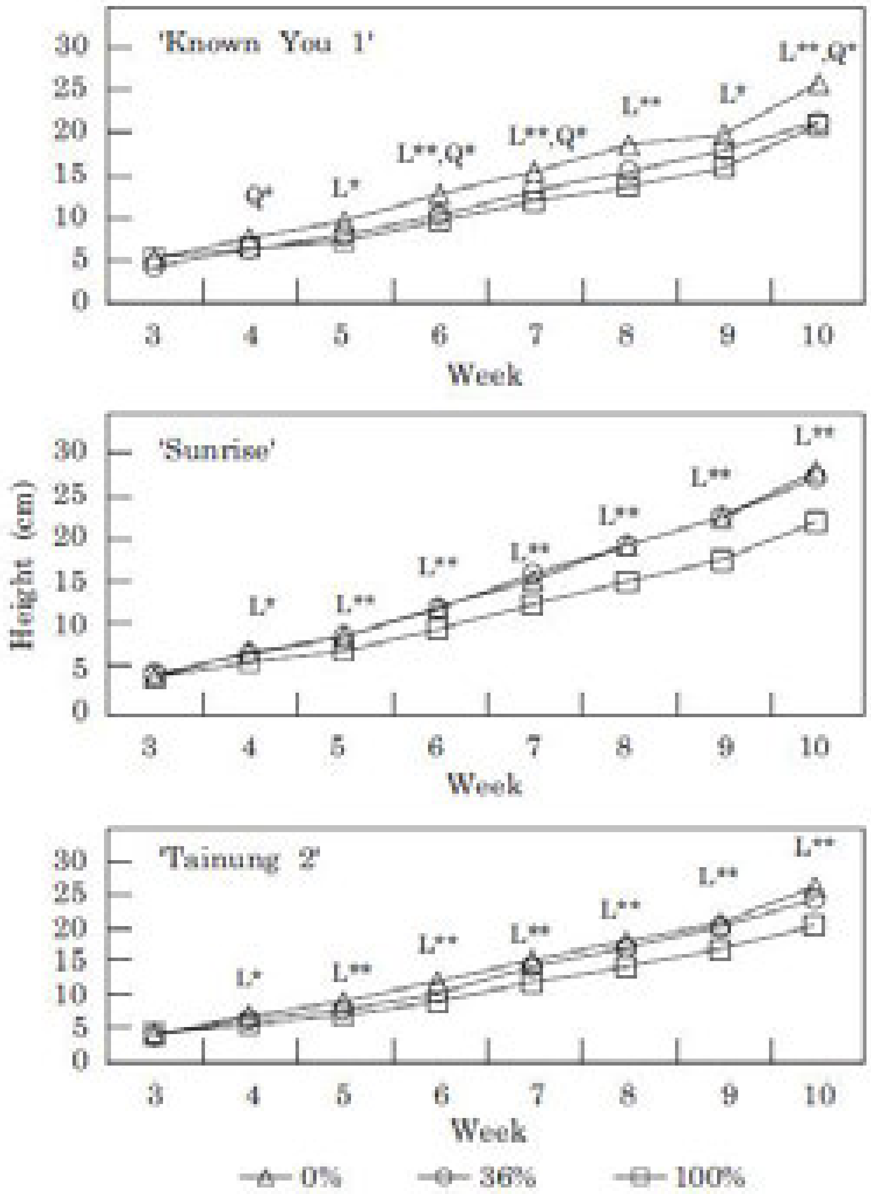


FIG. 1. Height of papaya seedlings receiving 0, 36 or 100 % wind exposure from 9 Mar. to 18 May 1996. Measurements began in week 3. *,** indicates linear (L) or quadratic (Q) regression models were significant at $P \leq 0.05$ or $P \leq 0.01$. $n = 6$.

Wind

TABLE 1. *Leaf (LDW), stem (SDW), root (RDW), and total (TDW) dry weights, and root:canopy ratio (RCR) of papaya seedlings receiving 0, 36 or 100% wind exposure from 9 Mar. 1996 to 18 May 1996*

	% Wind exposure				
Variable	0	36	100	Sig.	r^2
'Known You 1'					
LDW (g)	2·33	2·35	1·92	ns	
SDW (g)	1·25	1·18	0·90	L**	0·46
RDW (g)	3·12	3·30	3·78	ns	
TDW (g)	6·70	6·83	6·60	ns	
RCR	0·92	0·94	1·34	L**	0·42
'Sunrise'					
LDW (g)	1·95	2·11	1·72	ns	
SDW (g)	1·09	1·36	0·96	L* Q**	0·24, 0·69
RDW (g)	3·85	3·33	3·46	ns	
TDW (g)	6·89	6·81	6·05	ns	
RCR	1·27	0·97	1·36	Q**	0·45
'Tainung 2'					
LDW (g)	2·05	2·29	1·61	L**Q**	0·38, 0·67
SDW (g)	1·63	1·24	0·77	L*	0·22
RDW (g)	3·14	3·87	3·32	ns	
TDW (g)	6·81	7·39	5·70	ns	
RCR	0·97	1·15	1·40	ns	

ns, *, ** Indicates non-significant, or linear (L) or quadratic (Q) regression models are significant at $P \leqslant 0{\cdot}05$ or $P \leqslant 0{\cdot}01$, respectively. $n = 6$.

TABLE 2. *Height (Ht), leaf (LDW), stem (SDW), and root (RDW) dry weight, dry weight gain, leaf area (LA), root : canopy ratio (RCR), and daytime and night-time whole plant evapotranspiration (E_{wp}) of papaya seedlings receiving 0 36 or 100 % wind exposure from 11 Nov. to 16 Dec. 1995*

Variable	% Wind exposure 0	36	100	Sig.	r^2
'Known You 1'					
Ht (cm)	40·7	39·2	30·8	L*	0·33
LDW (g)	4·76	5·02	2·85	L**	0·36
SDW (g)	3·04	3·24	2·24	ns	
RDW (g)	5·80	5·50	4·39	ns	
Dry wt (g)	13·32	13·46	9·19	L*	0·25
RCR	0·78	0·69	0·91	ns	
LA (cm^2)	1186	1311	767	L*	0·30
Day E_{wp} ($mg\ m^{-2}\ s^{-1}$)	77·1	70·8	49·0	L**	0·83
Night E_{wp} ($mg\ m^{-2}\ s^{-1}$)	3·6	3·7	5·7	L**Q**	0·86, 0·95
'Sunrise'					
Ht (cm)	47·0	46·5	41·3	L**	0·49
LDW (g)	4·18	4·93	3·57	Q**	0·49
SDW (g)	3·46	4·39	2·72	Q**	0·54
RDW (g)	4·61	6·06	5·08	ns	
Dry wt (g)	12·04	15·18	11·15	Q**	0·60
RCR	0·60	0·67	0·81	L*	0·24
LA (cm^2)	1112	1186	936	L*,Q*	0·27, 0·43
Day E_{wp} ($mg\ m^{-2}\ s^{-1}$)	74·7	62·7	57·6	L**Q**	0·67, 0·79
Night E_{wp} ($mg\ m^{-2}\ s^{-1}$)	4·0	3·6	5·9	L**,Q**,	0·63, 0·84
'Tainung 2'					
Ht (cm)	46·8	45·5	40·0	L**	0·42
LDW (g)	5·13	5·62	4·75	ns	
SDW (g)	3·75	4·76	3·62	ns	
RDW (g)	6·20	6·84	6·37	ns	
Dry wt (g)	14·84	16·98	14·49	ns	
RCR	0·69	0·72	0·77	ns	
LA (cm^2)	1326	1482	1086	ns	
Day E_{wp} ($mg\ m^{-2}\ s^{-1}$)	84·9	71·7	54·6	L**	0·87
Night E_{wp} ($mg\ m^{-2}\ s^{-1}$)	3·0	3·6	5·6	L**	0·83

ORIGINAL ARTICLE

Effects of indol butyric acid concentration on propagation from cuttings of papaya cultivars 'Golden' and 'Uenf/Caliman 01'

Omar Schmildt[1], Eliemar Campostrini[2], Edilson Romais Schmildt[1], Alena Torres Netto[2], Anderson Lopes Peçanha[1], Tiago Massi Ferraz[2], Geraldo Antônio Ferreguetti[3], Rodrigo Sobreira Alexandre[1] and Julián Cuevas González[4,*]

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Fruits, 2016, vol. 71(1), p. 27-33

DOI: 10.1051/fruits/2015043

Figure 1. Cutting prepared for IBA treatment.

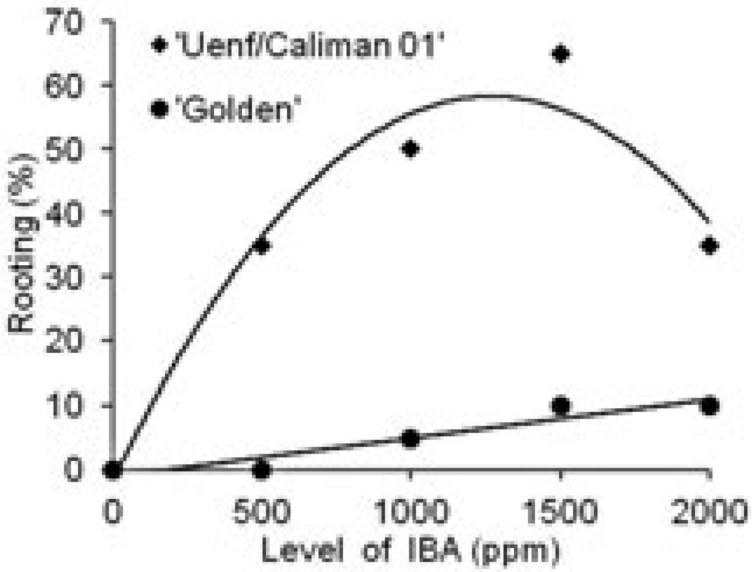

Figure 2. Rooting success in cvs 'Golden' and 'Uenf/Caliman 01', in response to different levels of IBA 70 days after treatment. $N = 120$ cuttings per cultivar (24 cuttings per cultivar and dose). Equations: 'Golden', $Y_i = -1.0 + 0.006x$, $R^2 = 0.90$; 'Uenf/Caliman 01', $Y_i = -1.57 + 0.093x - 0.000037x^2$, $R^2 = 0.95$.

28 dias

Table I. Vegetative characteristics of cv. 'Uenf/Caliman 01' papaya cuttings *versus* seedlings: plant height at transplanting (PH1) and after 4.5 months in the field (PH2), trunk diameter (Trunk), leaf number (Leaves) and canopy diameter (Canopy).

Propagation procedure	Vegetative characteristics[y]				
	PH1 (cm)	PH2 (cm)	Trunk (cm)	Leaves	Canopy (cm)
Cuttings	21.3 ± 0.9	67.2 ± 2.8	6.6 ± 0.3	21.3 ± 1.0	187.3 ± 9.9
Seeds	9.3 ± 0.3	126.8 ± 2.2	8.3 ± 0.3	25.2 ± 0.6	179.5 ± 3.8
P value[z]	< 0.0001	< 0.0001	0.0001	0.0027	0.4677

[y] Means ± standard errors ($n = 15$); [z] *t*-Student test.

Table II. Reproductive characteristics of cv. 'Uenf/Caliman 01' in papaya cuttings *versus* seedlings after 4.5 months growing in the field: flowering onset (Flowering, in days after transplanting - DAT), flowers per plant (Flowers), height for first fruit (HFruit), fruit number per plant (NbFruits), length of the portion of the stem bearing fruits (SRLength).

Propagation procedure	Reproductive characteristics[y]				
	Flowering (DAT)	Flowers	HFruit (cm)	NbFruits	SRLength (cm)
Cuttings	0.0 ± 0.0	12.3 ± 0.4	25.6 ± 2.3	9.7 ± 0.5	41.6 ± 3.1
Seeds	90.6 ± 1.2	15.4 ± 0.5	68.1 ± 1.4	12.8 ± 0.8	58.7 ± 2.6
P value[z]	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0002

[y] Means ± standard errors ($n = 15$); [z] *t*-Student test.

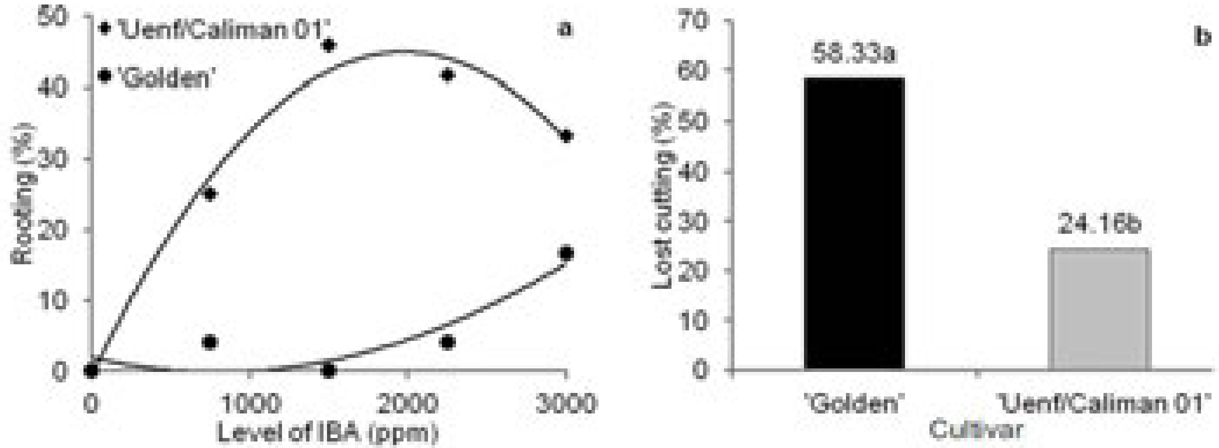

Figure 3. Rooting success 70 days after treatment in papaya cvs 'Golden' and 'Uenf/Caliman 01', in response to different concentrations of IBA. (a) Percentage of rooted cuttings. $N = 120$ cuttings per cultivar (24 cuttings per cultivar and dose). Equations: 'Golden', $Y_i = 1.9054 - 0.0051x + 0.0000032x^2$, $R^2 = 0.83$; 'Uenf/Caliman 01', $Y_i = -0.5957 + 0.046x - 0.00001164x^2$; $R^2 = 0.98$; (b) Losses due to stem rot. Means followed by different letters are significantly different. Separation of means by Tukey test ($P < 0.05$).

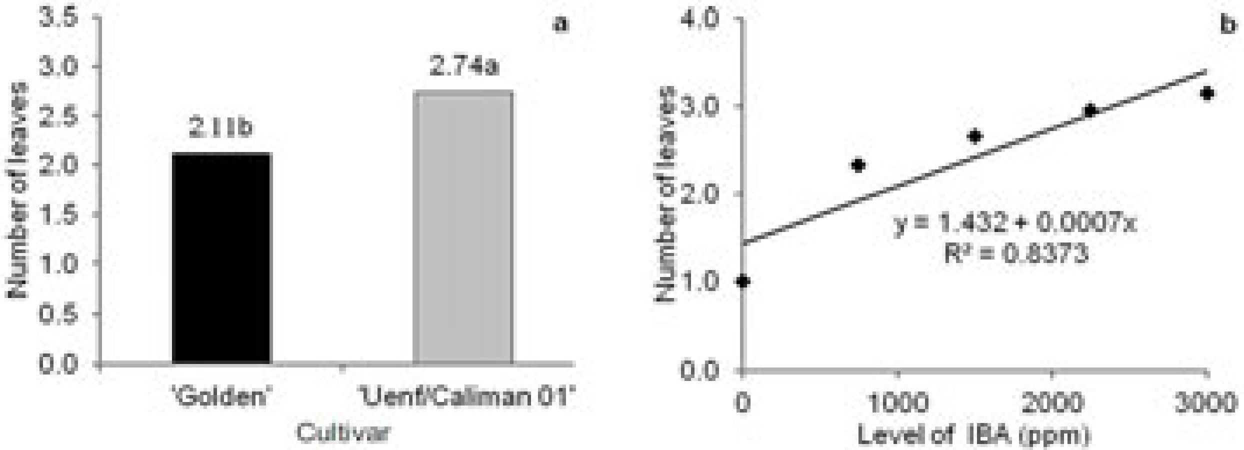

Figure 4. Leaf number in cvs 'Golden' and 'Uenf/Caliman 01' cuttings after 70 days of acclimatization: (a) Cultivar comparison; (b) Effect on leaf number of the levels of IBA applied to the base of 'Uenf/Caliman 01' cuttings. Means followed by different letters are significantly different. Separation of means by Tukey test ($P < 0.05$). N = 120 cuttings per cultivar (24 cuttings per cultivar and dose).

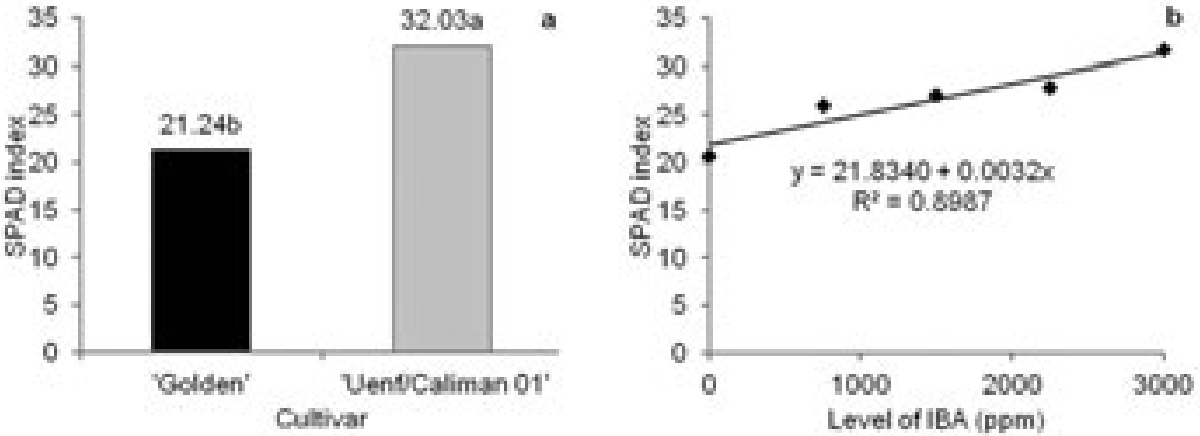

Figure 5. Chlorophyll content estimated by SPAD values in cvs 'Golden' and 'Uenf/Caliman 01' cuttings after 70 days of acclimatization: (a) Cultivar comparison; (b) Effect on SPAD values of the levels of IBA applied to the base of 'Uenf/Caliman 01' cuttings. Means followed by different letters are significantly different. Separation of means by Tukey test ($P < 0.05$). $N = 120$ cuttings per cultivar (24 cuttings per cultivar and dose).

Table III. Linear correlation of the cutting height, cutting diameter, leaf number and root volume with photosynthesis rate (A) and efficiency of photosystem II (FV/Fmax ratio) in papaya cvs 'Golden' and 'Uenf/Caliman 01'.

Variables	A (μmol CO_2 m^{-2} s^{-1})		Fv/Fmax ratio	
	Golden (n = 9)	Uenf/Caliman 01 (n = 37)	Golden (n = 9)	Uenf/Caliman 01 (n = 37)
Cutting height	0.3413^{ns}	-0.0280^{ns}		
Cutting diameter	0.7499^{**}	0.2053^{ns}		
Leaf number	0.8409^{**}	0.4266^{**}	0.0962^{ns}	-0.2745^{ns}
Root volume	0.2666^{ns}	0.2912^{ns}	0.0270^{ns}	-0.0962^{ns}

ns = not significant at 5% by *t*-test; ** significant at 1% by *t*-test.

Conclusões

Em estacas de mamoeiro 'Golden', em novos estudos, e para a indução de enraizamento, indica-se aumentar a concentração de AIB acima de 3000 mg L^{-1};

Estacas de mamoeiro 'Uenf/Caliman 01' enraízaram 65% quando tratadas com AIB a 1500 mg L^{-1}; Poucas raízes nas estacas do mamoeiro são suficientes para manter um bom estado hídrico, uma boa taxa fotossintética, uma significativa quantidade de clorofilas nas folhas e com boa eficiência na utilização de energia luminosa;

Plantas de mamoeiro propagadas por estaquia, quando cultivadas no campo apresentaram iniciação precoce de flores, menor altura de inserção dos primeiros frutos e baixa estatura, o que antecipa e facilita a colheita.

Gas-Exchange and Photochemical Efficiency in Seedling and Grafted Papaya Tree Grown under Field Condition

Proc. IInd IS on Papaya
Eds.: N. Kumar et al.
Acta Hort. 851, ISHS 2010

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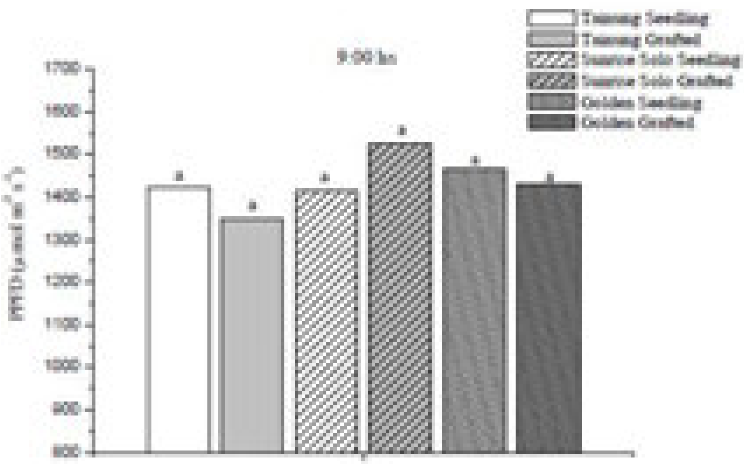
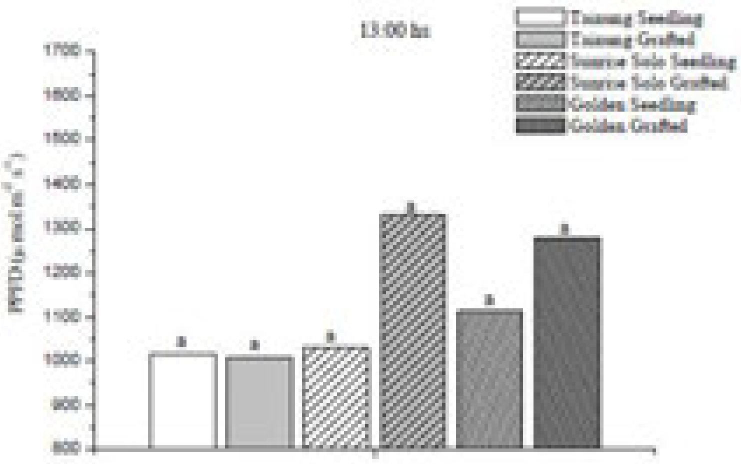
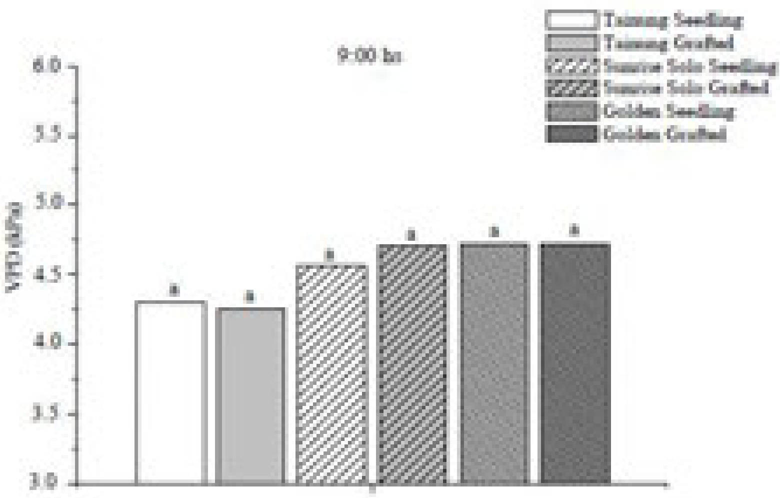
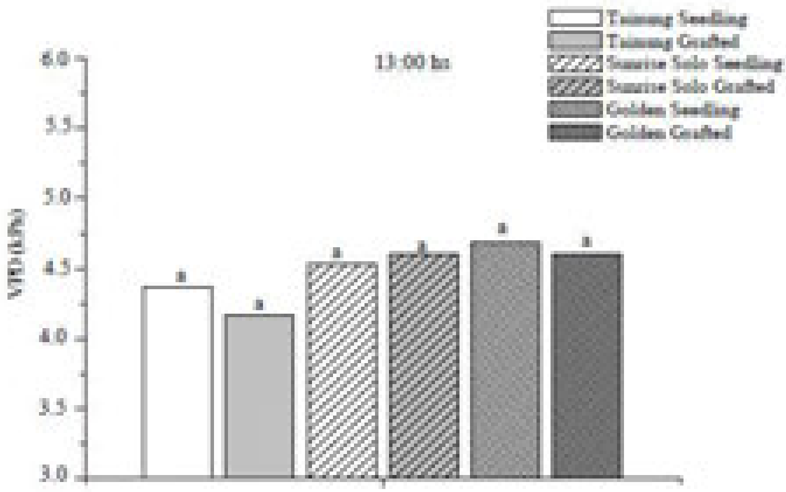
Table 1. Grafting treatments.

Scion/stock combination	Treatment code
Tainung seedlings	TS
Tainung 01/Tainung 01	TT
Sunrise Solo seedlings	SSS
Sunrise Solo/Tainung 01	SST
Golden seedlings	GS
Golden/Tainung 01	GT


9:00 hs
PPFD (μmol m-2 s-1)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
Tainung Seedling
Tainung Grafted
Sunrise Solo Seedling
Sunrise Solo Grafted
Golden Seedling
Golden Grafted


13:00 hs
PPFD (μmol m-2 s-1)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
Tainung Seedling
Tainung Grafted
Sunrise Solo Seedling
Sunrise Solo Grafted
Golden Seedling
Golden Grafted


9:00 hs
VPD (kPa)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
Tainung Seedling
Tainung Grafted
Sunrise Solo Seedling
Sunrise Solo Grafted
Golden Seedling
Golden Grafted


13:00 hs
VPD (kPa)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
Tainung Seedling
Tainung Grafted
Sunrise Solo Seedling
Sunrise Solo Grafted
Golden Seedling
Golden Grafted

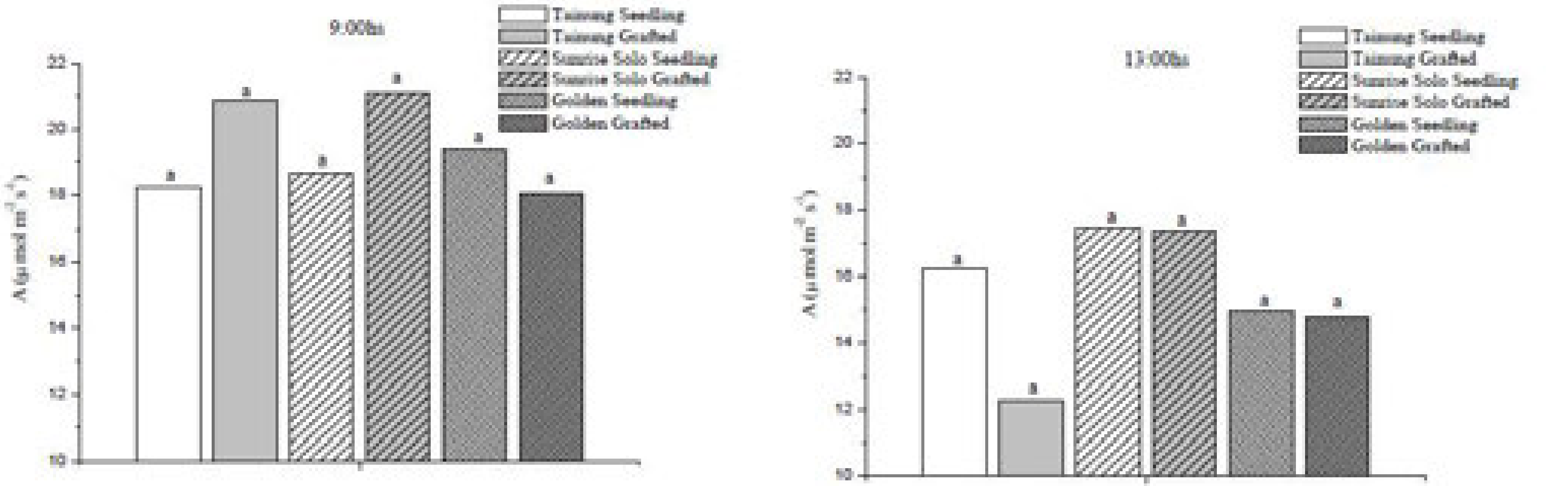
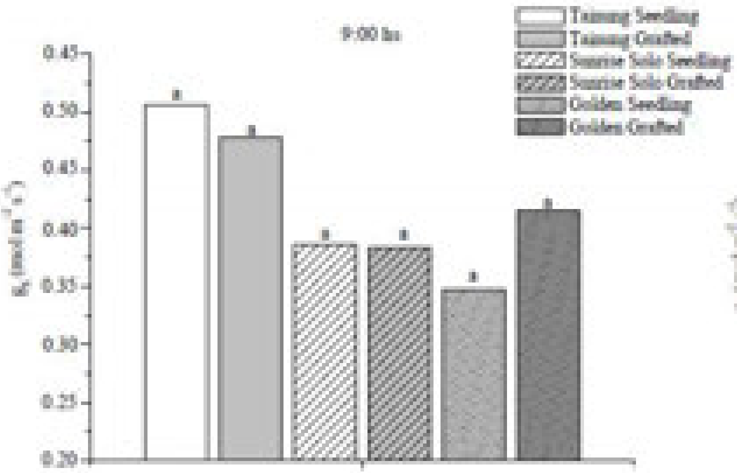
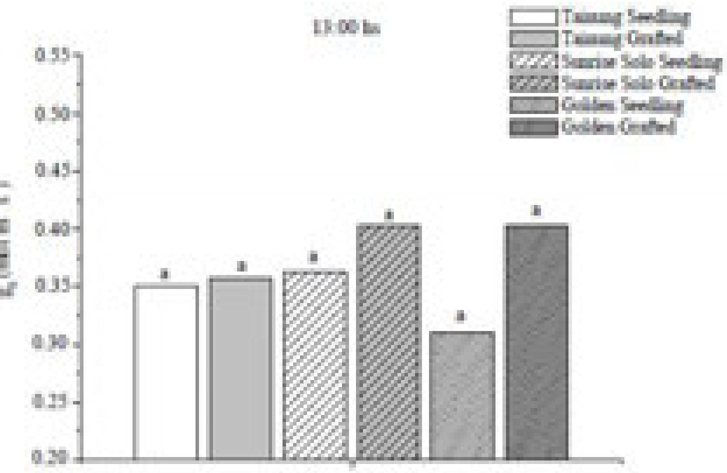
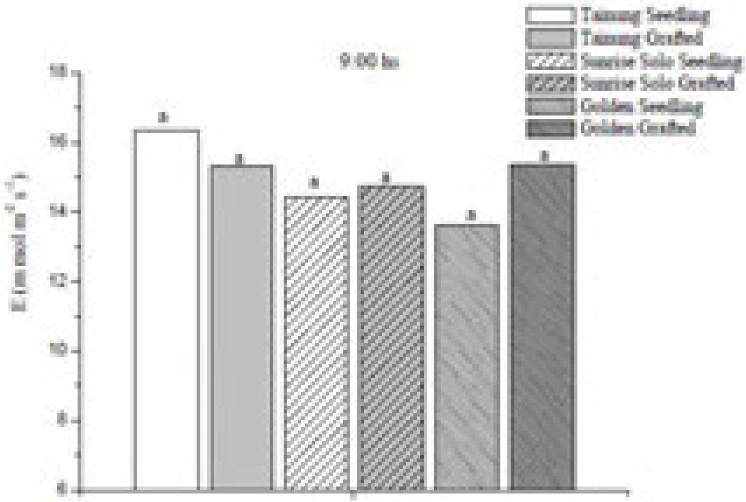
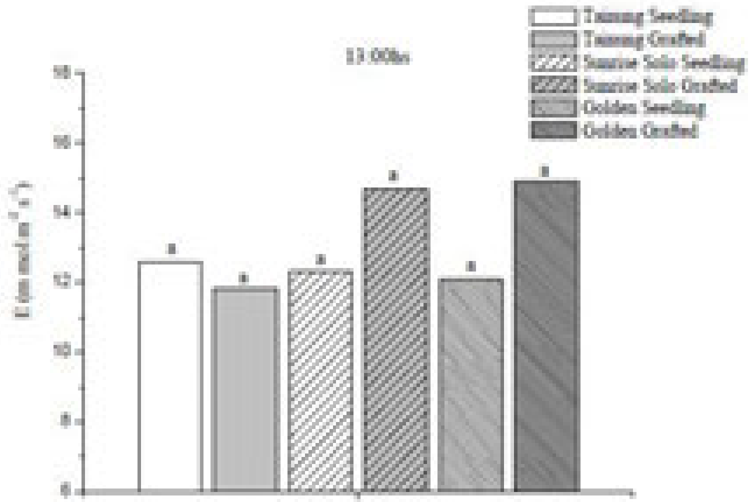


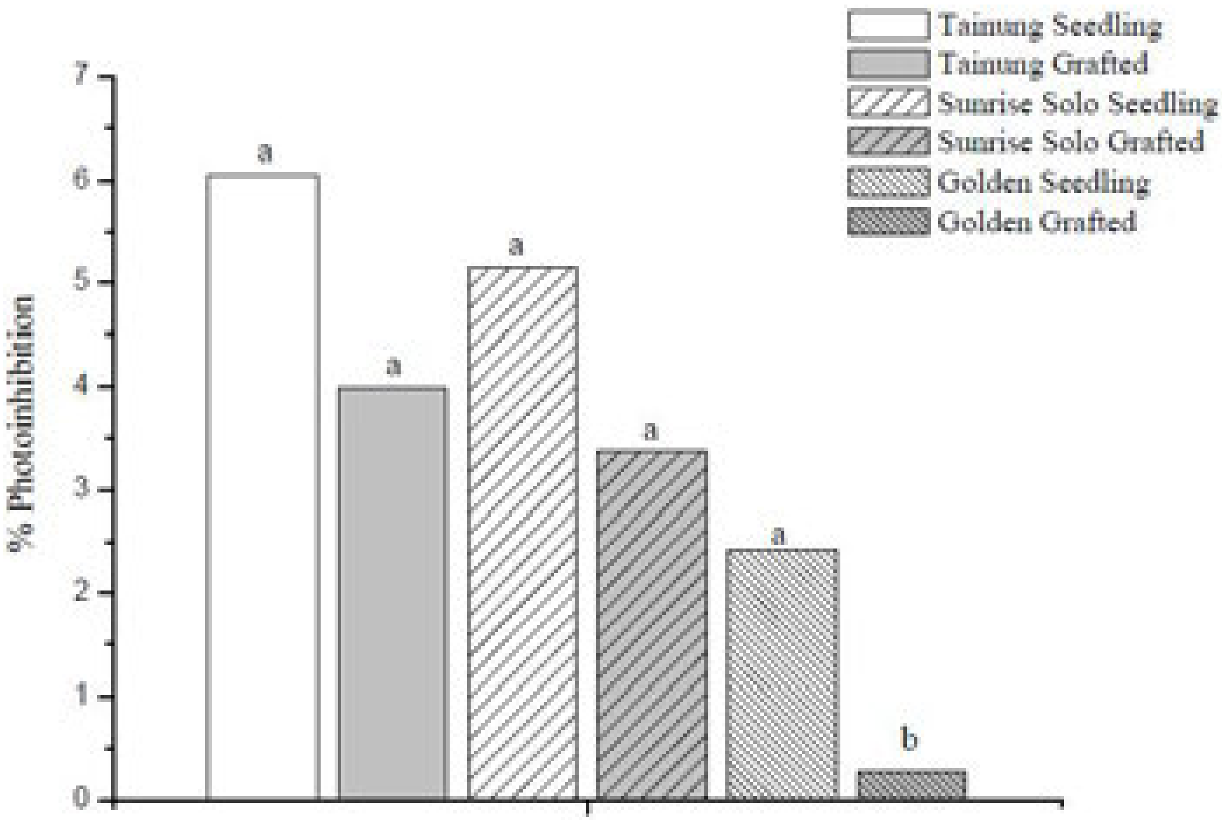
Fig. 1. Photosynthetic photon flux density (PPFD), leaf-to-air vapor pressure deficit ($VPD_{leaf-air}$), net photosynthetic rate (A) in papaya (*Carica papaya* L) cv. Golden, cv. Sunrise Solo and hybrid Tainung 01 grafted on open pollinated Tainung 01 (F2) seedlings and their respective seedlings (*n*=4). Means followed by the same letter are not significantly different, Tukey's test 5%.


9:00 hs
Tainung Seedling
Tainung Grafted
Sunrise Solo Seedling
Sunrise Solo Grafted
Golden Seedling
Golden Grafted
g_s (mol m^{-2} s^{-1})
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.45


13:00 hs
Tainung Seedling
Tainung Grafted
Sunrise Solo Seedling
Sunrise Solo Grafted
Golden Seedling
Golden Grafted
g_s (mol m^{-2} s^{-1})
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55


9:00 hs
Tainung Seedling
Tainung Grafted
Sunrise Solo Seedling
Sunrise Solo Grafted
Golden Seedling
Golden Grafted
E (m mol m^{-2} s^{-1})


13:00hs
Tainung Seedling
Tainung Grafted
Sunrise Solo Seedling
Sunrise Solo Grafted
Golden Seedling
Golden Grafted
E (m mol m^{-2} s^{-1})



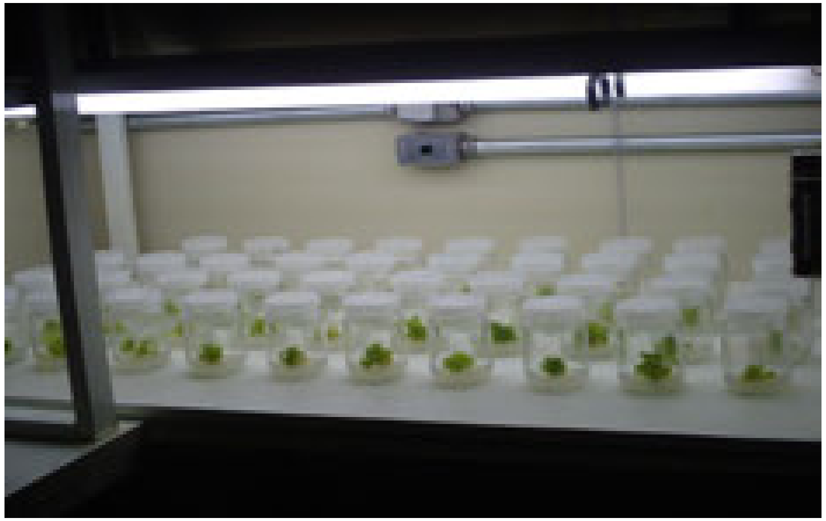
$$\% \text{ photoinhibition} = [1 - (F_v / F_{m\ 13:00}) / F_v / F_{m\ 9:00})] \times 100$$

CONCLUSIONS

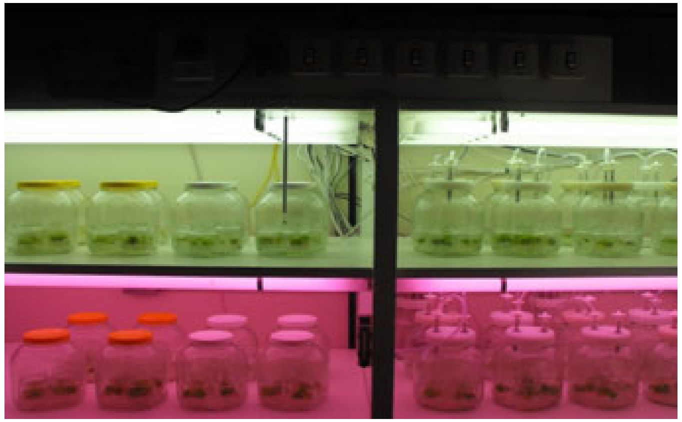
Transpiration and stomatal conductance were not affected by rootstock which means that grafting does not jeopardize the water intake in all papaya trees and the new xylem connection seems to maintain stable the root-trunk-atmosphere system. The results suggest that the performance of the grafted plants during the period was due to the capacity of the root system of Tainung 01 to provide water to the shoot and a good vascular connection between the scion and rootstock thereby maintaining high gas exchange and photochemical efficiency in the leaves and consequently a greater carbon gain.

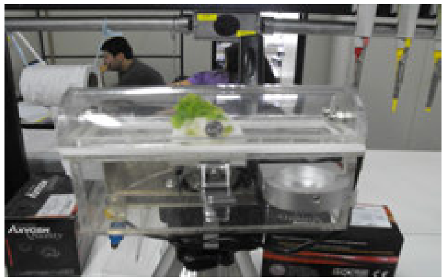
Theor. Exp. Plant Physiol.
DOI 10.1007/s40626-014-0026-y

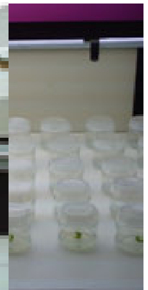
Photosynthetic capacity, growth and water relations in 'Golden' papaya cultivated in vitro with modifications in light quality, sucrose concentration and ventilation

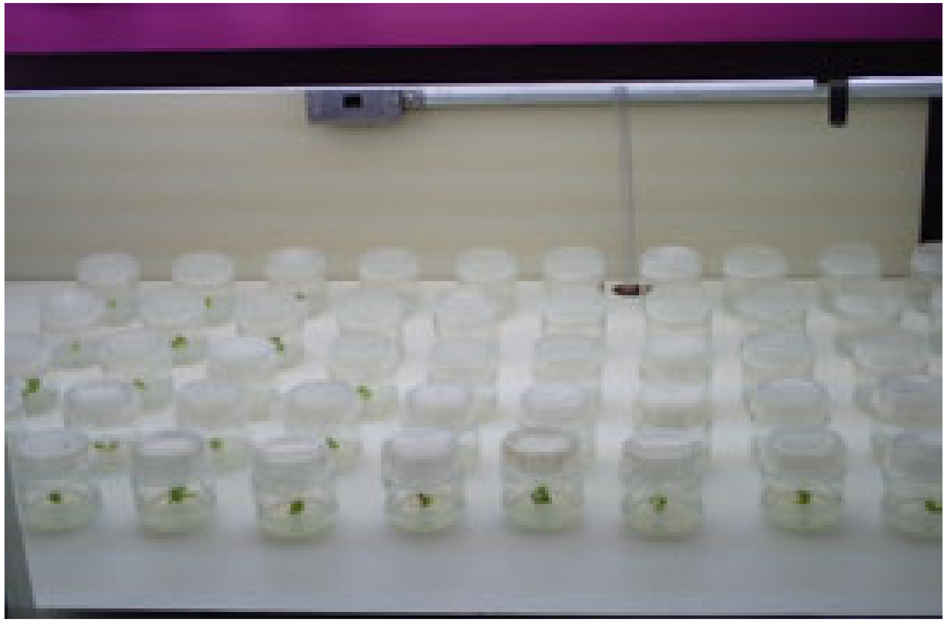


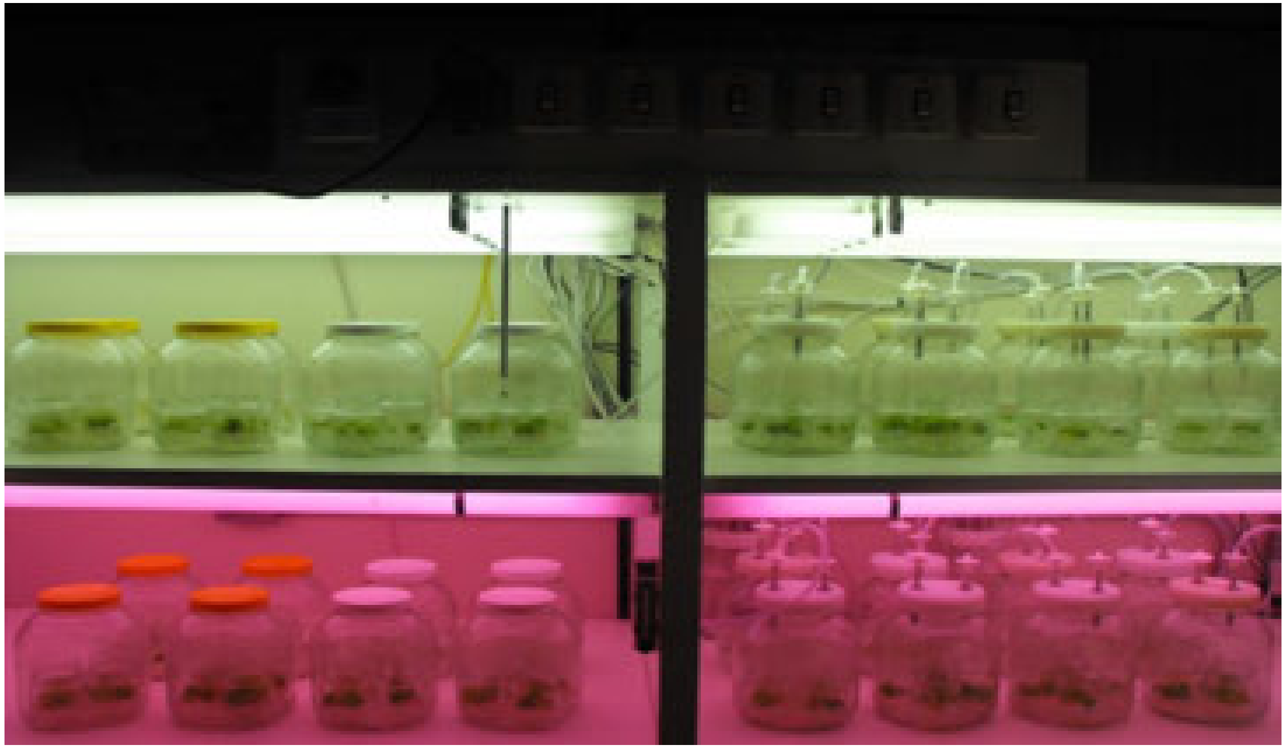
Omar Schmildt · Alena Torres Netto · Edilson Romais Schmildt ·
Virginia Silva Carvalho · Wagner Campos Otoni ·
Eliemar Campostrini

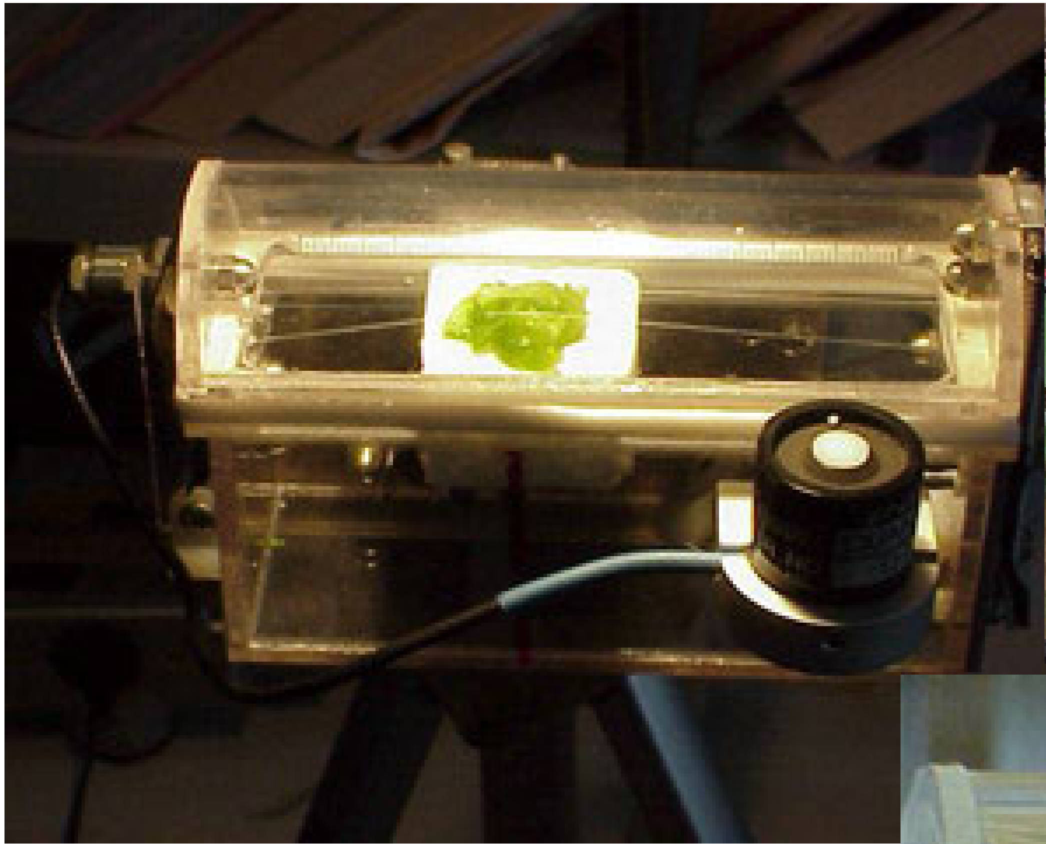


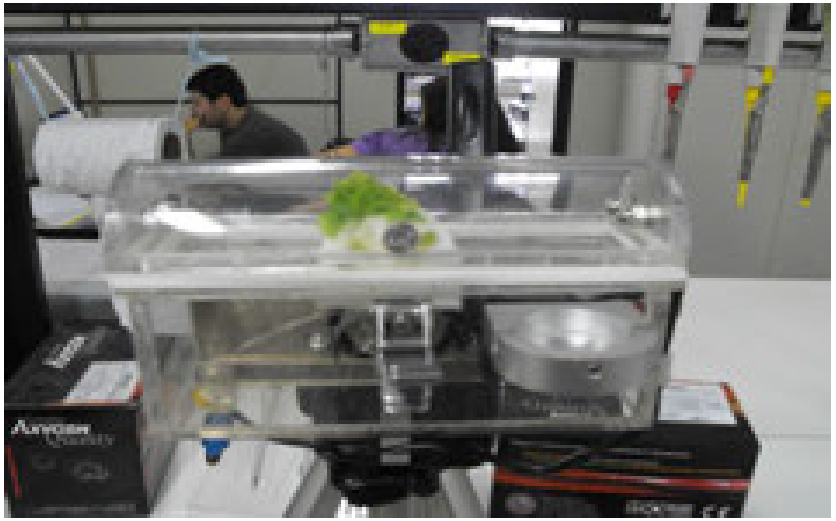
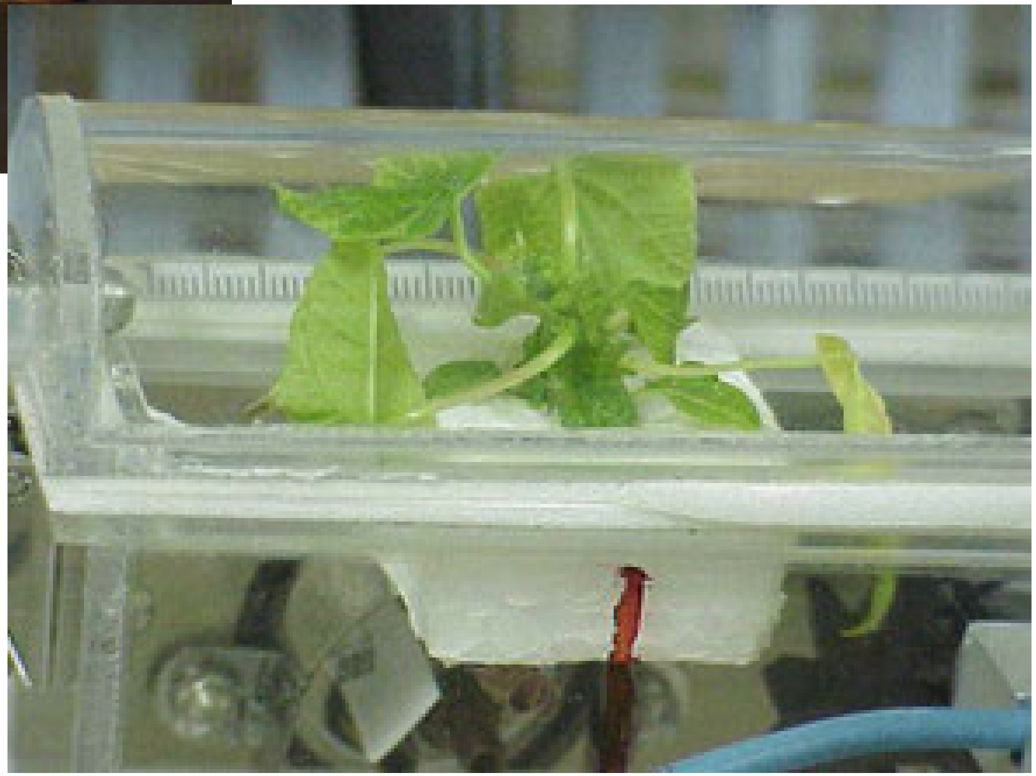










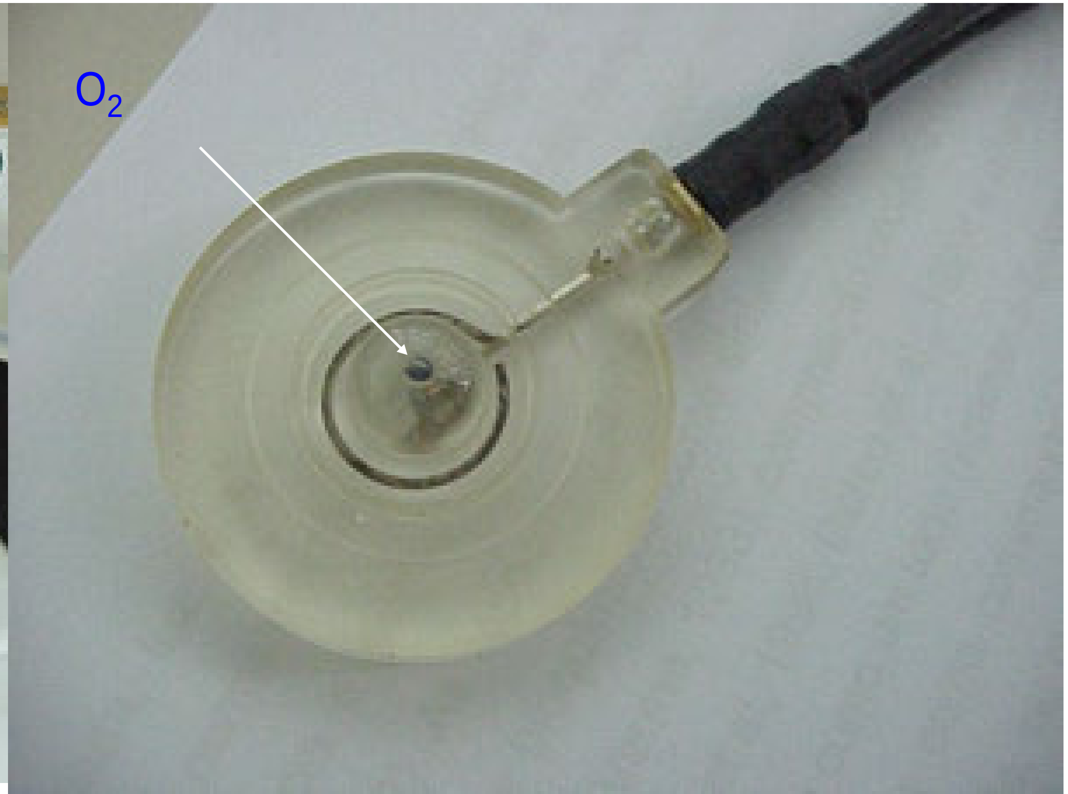
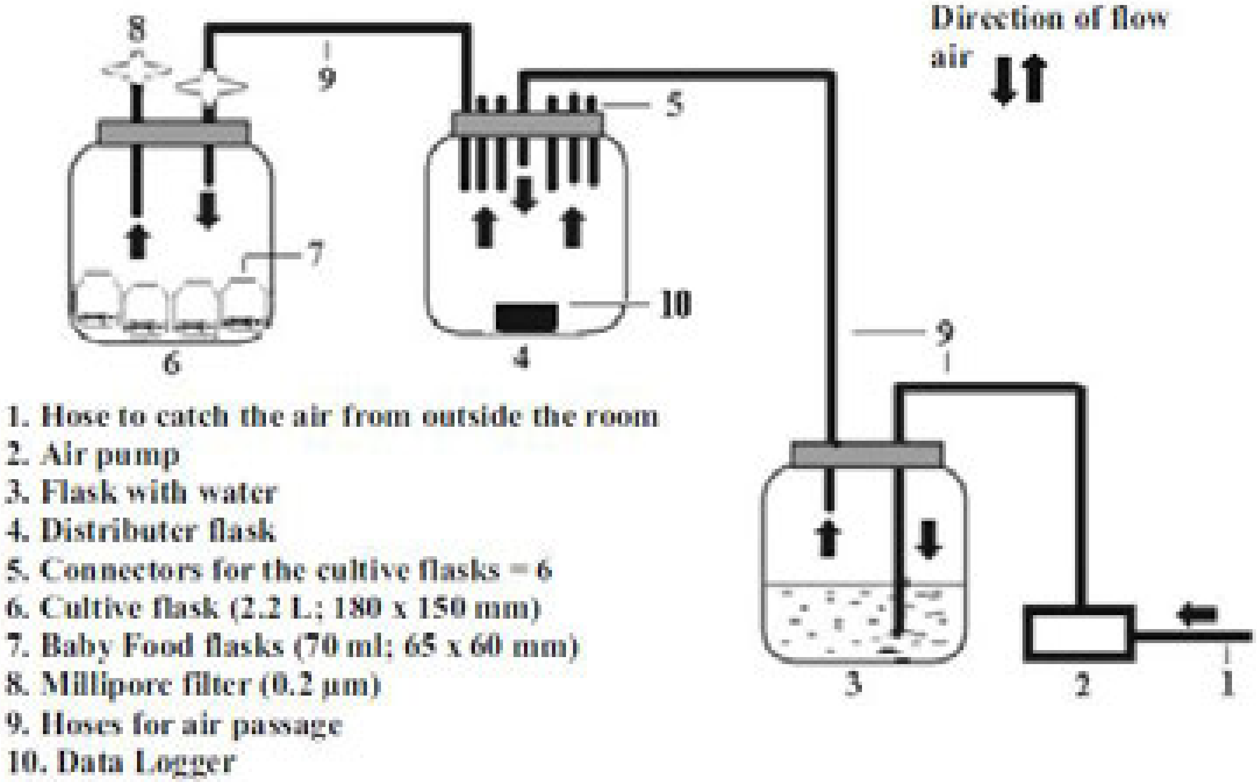

O2

Fig. 2 A forced-air circulation system (ventilated system) used for culturing seedlings in vitro



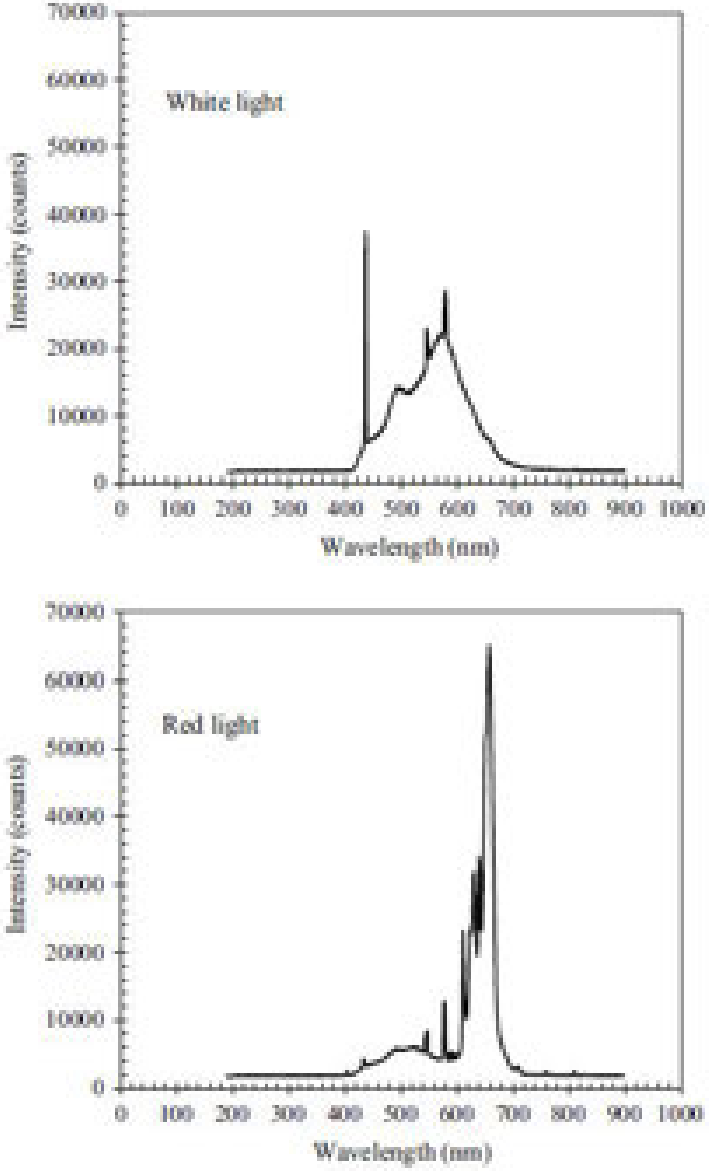


Fig. 1 Spectral energy distribution of *white* and *red lights* provided by fluorescent *white* lamps and *red* Grolux lamps respectively. Both provided a photosynthetic photon flux density of 90 μmol m^{-2} s^{-1}

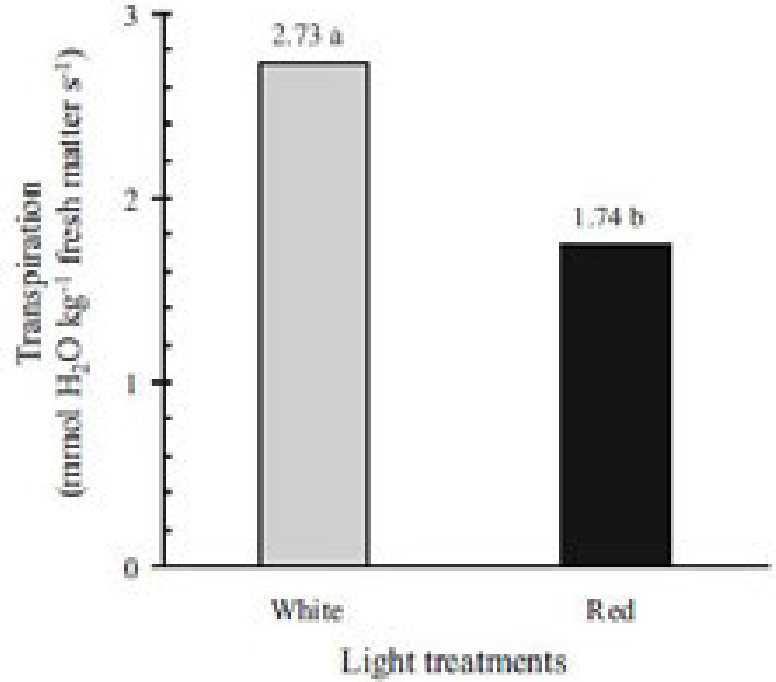


Fig. 3 Transpiration (E) in 'Golden' papaya plantlets cultured in vitro in MS multiplication culture medium under *white* or *red light*

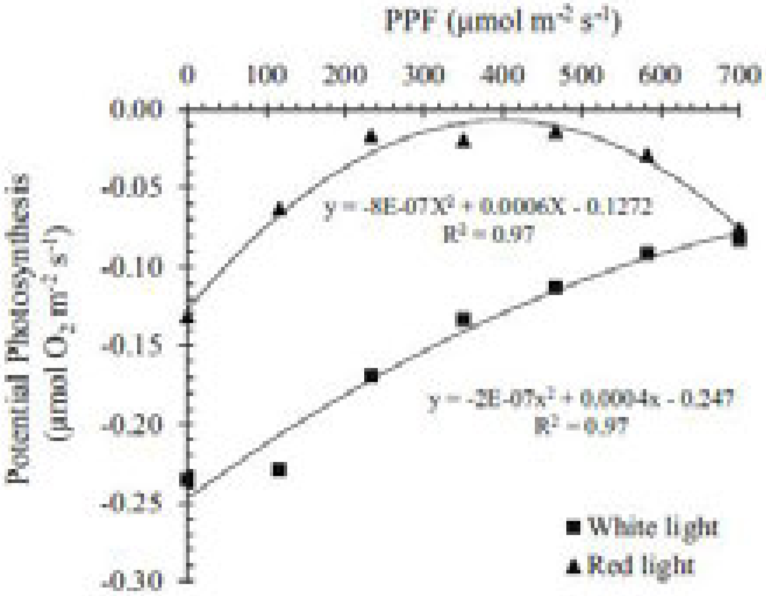


Fig. 4 The potential photosynthetic rate (µmol O_2 m^{-2} s^{-1}) in relation to the photosynthetic photon flux in 'Golden' papaya plantlets cultured in vitro in MS multiplication culture medium under *white* or *red light*

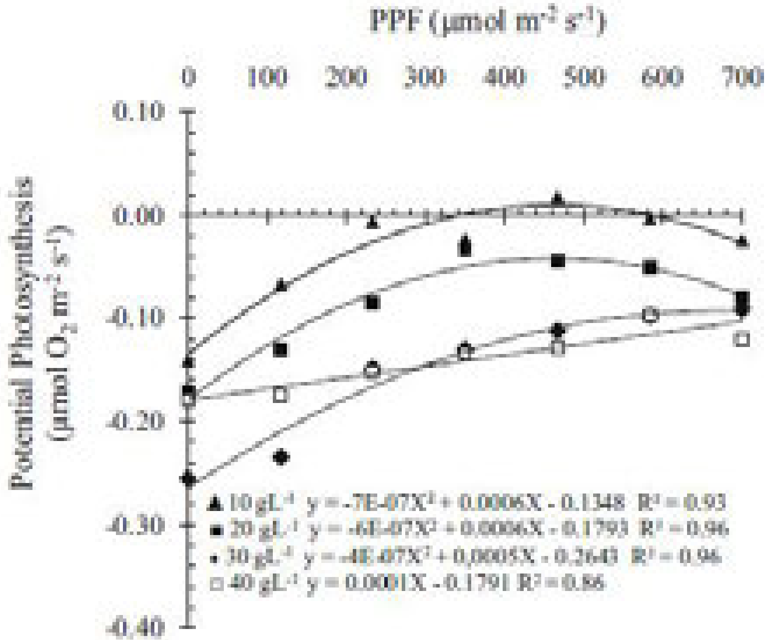


Fig. 6 The potential photosynthetic rate (µmol O_2 m^{-2} s^{-1}) in 'Golden' papaya plantlets leaves cultured in vitro in MS multiplication culture medium containing different light intensities and sucrose concentrations

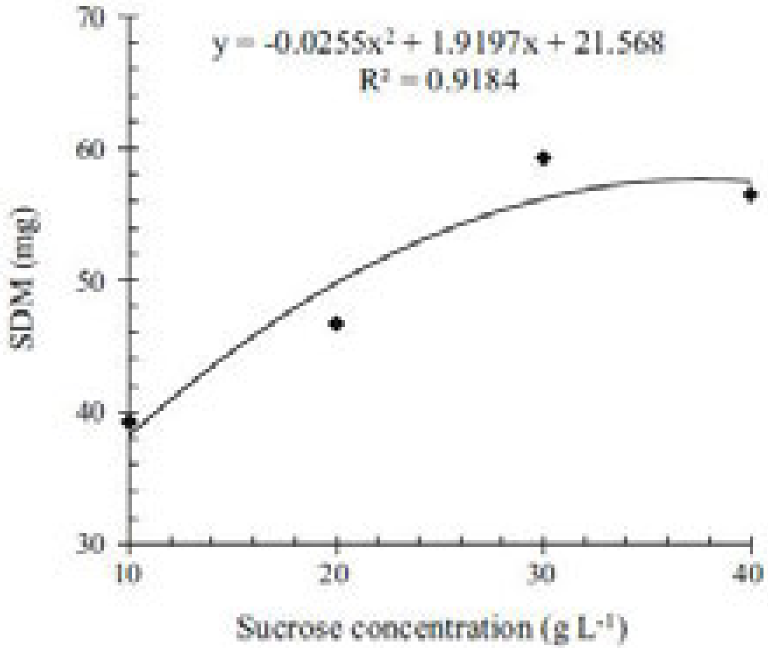


Fig. 5 Shoot dry matter (SDM) of 'Golden' papaya plantlets cultured in vitro in MS multiplication culture medium containing different sucrose concentrations

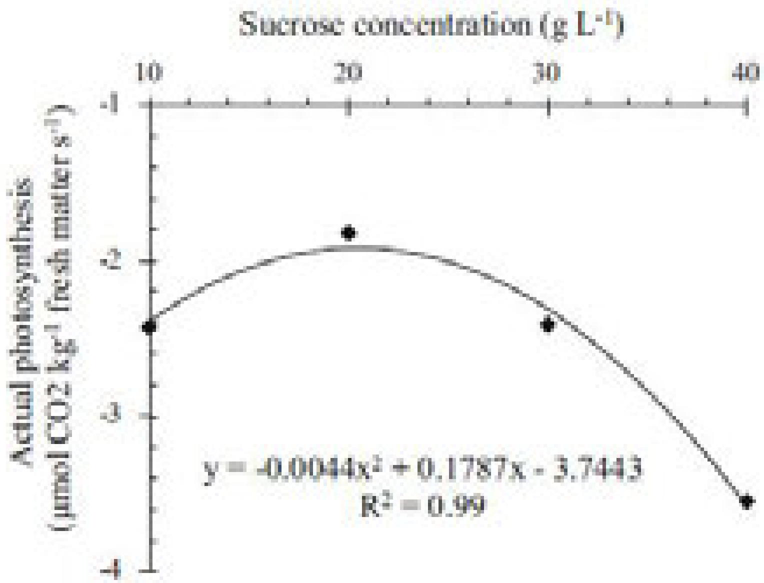


Fig. 7 The actual photosynthetic rate (A) (µmol of CO_2 kg^{-1} of fresh matter s^{-1}) of 'Golden' papaya plantlets leaves cultured in vitro in MS multiplication culture medium containing different sucrose concentrations

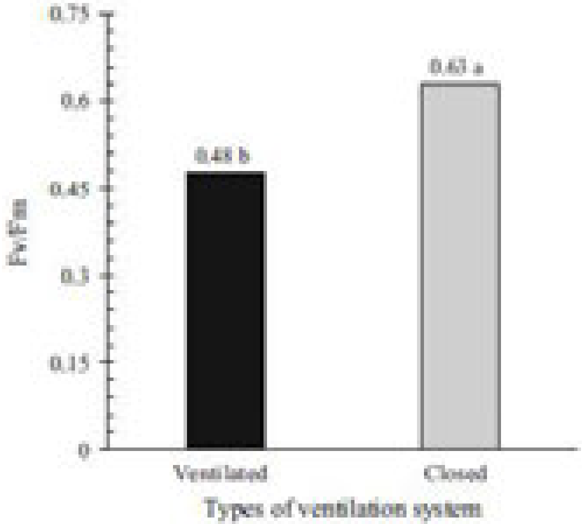


Fig. 8 The quantum efficiency in open photosystem II centres (F_v/F_m) in 'Golden' papaya plantlets cultured in vitro in MS multiplication culture medium in ventilated or closed systems

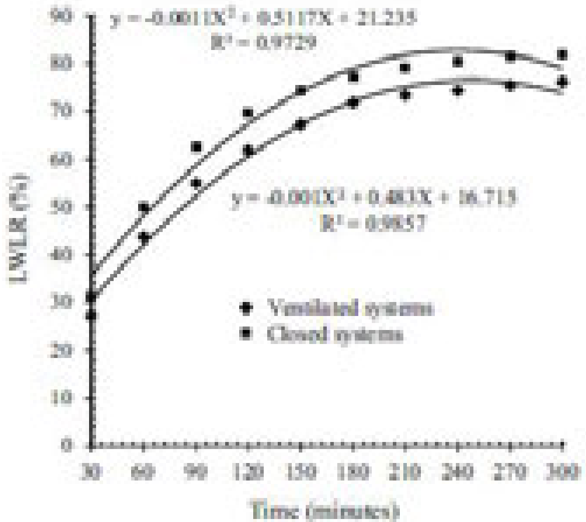


Fig. 9 The leaf water loss rate (LWLR) in 'Golden' papaya plantlets cultured in vitro in MS multiplication culture medium in ventilated or closed systems

In the present study, the increase in papaya dry matter production was due to the exogenous carbon provided by sucrose in the culture medium. No photosynthetic carbon assimilation or oxygen evolution by PS II was observed. This photochemical damage was attributable to the reduced maximum PS II quantum yield and the efficiency of the oxygen-evolving complex (OEC). We hypothesized that the reduced assimilation of carbon may have occurred due to the decreased activity in the Calvin-Benson cycle. Such damage to photosynthetic capacity was related to the presence of sucrose in the culture medium. The attempt to induce photoautotrophic metabolism in the papaya seedlings by the use of ventilated culture flasks, reduced sucrose (10 g L^{-1}) and a PPF of 90 μmol m^{-2} s^{-1} was not successful. In this species, alternative strategies to achieve a photoautotrophic metabolism and the expected biomass gain include the use of a greater photosynthetic photon flux density and an increased CO_2 concentration in the ventilated flasks in association with a markedly lower concentration (<10 g L^{-1}), or even the absence of sucrose in the culture medium.